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**STRATEGIC PETROLEUM RESERVE (SPR)
CAVERN AND WELL CREEP-CLOSURE TESTS**

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Abstract

This report briefly describes **the history of West Hackberry cavern 11 and well 112**, describes a creep/closure test, and presents the **results of the test. At the test conditions from October 1981 through October 1983, cavern 11 produced an average of 60 barrels of brine per day. At the test conditions from March 1982 through August 1982, well 112 produced an average of 1 gallon of brine per day.**

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Introduction

The development of mathematical models for prediction of cavern and well behavior must include predictions of closure due to salt creep as a function of pressure and time. In an effort to obtain actual field data for model verification, we decided to collect data from West Hackberry cavern 11 and well 112. Wells and caverns from other sites will also be evaluated in an effort to determine the effects of cavern shape, depth, salt properties, temperature, and possibly other variables. These data will provide the baseline for instrumentation performance and the baseline for cavern performance which is to be measured as part of the long-term monitoring plan.

History and Background

Well 11 was originally completed in 1962 as a brine producing well (Ref. 1). A well 11 workover in 1979 (Ref. 2) reconfigured the well but retained the 9 5/8 inch casing, and the well has been used as a slick hole. The cavern was formed through well 11 prior to mid-1977. The location of the cavern is shown in Figure 1, the cavern critical dimensions are shown in Figure 2, and well 11 configuration is shown in Figure 3.

Well 1 IA was completed in November 1978 (Ref. 3) and entered the cavern at 2943 ft. The well configuration is shown in Figure 4. Well 11B was completed in January 1979 (Ref. 4) and entered the cavern at 2959 ft. The well configuration is shown in Figure 5.

There were 6.5×10^6 bbl of sour crude in the cavern in September 1978 (Ref. 5), 6.4×10^6 bbl in December 1978, 7.5×10^6 bbl in April 1980, and 8.1×10^6 bbl in September 1980. Another 38,000 bbl were added in October 1981 to bring the total oil to 8.2×10^6 bbl.

Well 11-B was logged in November 1979 and showed an oil/brine interface at 3530 ft and an oil temperature of 101.5°F. The cavern was relogged in June 1980 and showed an oil/brine interface at 3614 ft and an oil temperature of 98°F. The cavern was relogged in June 1983 and showed an oil/brine interface at 3678 ft. A temperature log in September 1983 showed an oil temperature of 109°F. (Interface movement = 1.8 ft/mo and temperature increase = 0.28°F/mo since June 1980.)

Well 112 was completed in March 1981 (Ref. 6) to a depth of 5060 ft. The well configuration is shown in Figure 6. There was no piping connected to this well in March 1982, and it is therefore assumed to be configured as shown in Figure 6.

The descriptive information concerning the site is contained in the Site Characterization Report (Ref. 7) which was published in October 1980 and will be updated in 1983 with additional material properties data, revised salt contours, and other information.

The testing for cavern 11 closure was started in October 1981 when the cavern was shut in to allow the pressure to build up by cavern closure and then allow expansion of the oil. Prior to this time, the brine valves were open to the site brine line and the cavern brine pressure followed the brine line pressure.

The testing for well 112 closure was started when the well was shut in by the driller in March 1981, but the first brine bleed down was in April 1982. Effects due to thermal expansion of the brine in the well are considered negligible because the well fluids should have had adequate time to approach thermal equilibrium.

Testing WH Cavern 11

The test procedure that we use is to shut in the cavern to let the pressure increase and then bleed brine off to reduce the pressure as low as practical. The pressure instrumentation provides measurements of wellhead pressure by dial gauges read by the on-site O & M contractor (POSSI) and by two transducers coupled to an automated recording system. Brine flow is measured using a 2-inch turbine meter with flow data going directly to a totalizer. A diagram of the piping system is shown in Figure 7. The block diagram of the first data collection system is shown in Figure 8. There were continuing problems with this automated data collection: therefore, the data presented are a combination of dial gauge data corrected to psia and data from the automated system. The problems included moisture in the electrical system, lack of temperature control on the electronics, and repeated shut downs of the 110 VAC site power to the instrumentation system. As a result of these problems a different data collection system was installed in February 1983. A block diagram of this data collection system is shown in Figure 8A. This data collection system operated properly from February 1983 to October 1983 when the test was terminated.

The pressure and bleed down data are shown in Figures 9 and 10. Analyses of these data provide the following typical parameters for cavern 11:

cavern elasticity = 49 bbl/psi

salt elasticity = 2×10^{-6} bbl/bbl psi

cavern closure plus thermal expansion rate = 60 bbl/day

cavern pressure increase rate = 1.5 psi/day

In the latter half of 1982 POSSI was performing surface piping modifications which required cavern **bleed down**. The pressure instrumentation could not provide data during this period **and the** brine withdrawal was not measured. In September 1983 POSSI **workover** activities to remove the salt plug that was found in well 11 **B** when logging was attempted precluded collection of reliable **brine pressure data at the manifold**. We added a transducer on the oil manifold **and** monitored oil pressure as shown in Figure 9C.

Comparison values for other caverns are shown in Table 2, and the calculational details are included in Appendix I. The cavern pressurization rate is a function of the cavern pressure and of the time since the last bleed down as shown **by the** typical **pressure** curve in Figure 11. The early **pressure** increase after a **bleed down** may also be a function of the magnitude of pressure change during bleed down. The curve in Figure 11 is significantly nonlinear during **the** first few **weeks** after bleed down. There are undoubtedly **many** contributing **factors** involved in this behavior, **but** there are contributions from **salt creep and** the salt stress redistribution **after any** change in pressure (temperature is **assumed to be constant**). In a static cavern **that has** reached a steady state condition, the difference between internal pressure **and** the external pressure creates a stress redistribution in the salt. **Any change** in internal (or external) pressure will **cause a change** in salt creep rate **and a** redistribution **of** salt stress to reestablish the **steady state** condition and this redistribution takes time. After this stress redistribution is "complete", the remaining factor which **causes the** cavern **pressure to** increase with time is salt creep (**temperature is assumed to be constant and** solutioning is assumed to be insignificant). A more **complete** discussion **of** creep **and** stress distribution is presented in Ref. 15.

The cavern pressure decrease during brine removal is typically linear **except** during the first portion of the bleed **down** as shown in Figure 12. The reason for this early non-linearity **has not been** established, but **phenomena** like fluid viscosity and/or salt inertia could generate similar **responses**.

The test on **WH 11** was terminated in October 1983 to allow the instrumentation to be calibrated and repaired prior to use **on** other cavern tests as directed **by DOE** Technical Directive Number 92.

Testing **WH 112**

During **testing we shut** in the well to let the pressure increase **and** then bled brine **off** to **reduce the** pressure as low as practical. **Wellhead** pressure data were obtained **from dial gauges** read **by POSSI**. The brine was bled into a five gallon container for volume **measurement**. The pressure and bleed **down data are shown in** Figures 13 and 14. Analyses **of these** data provide the following typical parameters for well 112:

well elasticity = **.007 bbl/psi = .28 gal/psi**

salt elasticity = 2.5×10^{-6} **bbl/bbl psi**

well closure rate = **.02 bbl/day = 1.0 gal/day**

well pressure increase rate = **3.7 psi/day**

The well pressure rise from March 1981 to April 1982 is **assumed to be 450 psi/413 day = 1.1 psi/day**. The plots of pressure vs time **and** volume vs pressure exhibit the same general curve shapes as **those for** cavern 11 except for an apparent increase in gal/psi at very low pressures as **shown** in Figure 14. This is probably due to reduced bleed **down** rates and high creep rates at low pressure.

The test on 112 was terminated in August 1982 when the surface piping construction effort was started. Several attempts were made to restart the test after construction was completed but the data showed no pressure increase. The lack of pressure rise could have been due to wellhead valve leakage or to some other unknown cause.

Mathematical Models

An attempt has been made to perform a thermal analysis of West Hackberry Cavern 11 so that the pressure changes due to thermal expansion could be estimated. In order to perform a thermal analysis, boundary condition temperatures in the adjacent salt are required. Unfortunately, no temperature logs in the vicinity of this cavern are available. As a result, very rough estimates had to be used. Some temperature logs taken in West Hackberry cavern 6 between March and September of 1980 were available. Analyses of these data indicated that the temperature field in the dome around the cavern was best represented by a temperature of 126°F at a depth of 3580 feet and a gradient of 0.012°F/ft. A similar temperature field was assumed to exist around West Hackberry cavern 11. There was no documented information within SPR of the leach or fill history of cavern 11 before July 1977. After this time a complicated oil fill schedule was recorded until October 1980. To simplify the calculations, this fill period was modeled in two stages: an oil fill to 6.4 million barrels in September 1978 and an oil fill to 8.2 million barrels in October 1980. The fill oil temperature was assumed to be 70°F in each case. The temperature calculations were carried out through July 1982. The calculated heat flux into the cavern at this time was 421,000 Btu/hr. Given this heat flux, the rates of temperature and pressure change can be calculated as follows:

Temperature rise : $\frac{dT}{dt} =$

$$\frac{421.000 \text{ BTU/hr} \times 24 \text{ hr/day}}{.464 \text{ BTU/lb}^\circ\text{F} \times 8.2 \times 10^6 \text{ bbl} \times 42 \text{ gal/bbl} \times 7 \text{ lb/gal}} = .01^\circ\text{F/day}$$

Pressure rise: $\frac{dp}{dt} =$

$$\frac{4.5 \times 10^{-4} \text{ bbl/bbl}^\circ\text{F} \times .01^\circ\text{F/day} \times 8.2 \times 10^6 \text{ bbl}}{49 \text{ bbl/psi}} = .8 \text{ psi/day}$$

It should be re-emphasized that without some comparative temperature checkpoints this kind of calculation is at best an estimate with a low confidence factor. Also, the above calculated rates are only approximately correct at one time (July 1982). The cavern temperature rise is expected to be asymptotic to some upper temperature value. Thus, dT/dt will decrease and approach zero as the temperature of the cavern approaches an equilibrium value. At the present time, detailed analyses are being conducted to determine the time dependent behavior of the cavern fluid temperatures. These calculations are being assessed against field measurement to ensure reliability. A summary of SPR temperature measurements is given in Ref. 16.

A finite element structural creep analysis of cavern 11 was performed using material properties obtained from the site. The creep of salt is highly dependent on temperature, so the calculation of creep coefficients included thermal effects. As discussed, detailed thermal analyses were not available. The creep analyses were, therefore, performed at two bounding temperatures. The lower bound was chosen as 72°F and the upper bound was chosen as 117°F.

The finite element program **calculates displacements at each requested time step. These displacements are added to the original** nodal coordinates and used to **compute a deformed** cavern volume. The deformed cavern volumes and times are **used to calculate** fluid flow rates or cavern pressure increases (when included with density, **mass and** compressibility of fluids in the cavern). The predicted daily pressure increase in **the** cavern corresponding **to the two different** temperatures are:

<u>Analysis Temperature (°F)</u>	<u>Predicted Pressure Increase (psi/day)</u>
72	0.7s
117	3.00

A curve fit (exponential relationship) of the calculations at **72°F** and 117°F gives a pressure increase at **100°F** of **1.7 psi/day** (Ref. 17).

The two models predict a greater pressure increase (**.8 + 1.7 = 2.5 psi/day**) than was actually measured. This discrepancy may indicate the need for some **adjustments** in the calculations **and** certainly indicates the **need** for cavern and temperature histories and for repeatable **creep/flow** field data.

The predictions for well 112 do not agree precisely with the field data, and it is **probable that some** redefinition **of the model may** be required. It is certain **that** additional field **data** are required **on multiple** wells and that these data should include **borehole temperatures. The calculated pressure rise is a function of** time since well completion **and of** well pressure. **The calculated** pressure rise is **0.9 psi/day at two months and 0.5 psi/day at six months** (compare to the previously discussed **3.7 psi/day** typical field observation).

Future Test Plans

We plan to expand the creep test program in early 1984 to include Sulphur Mines cavern 6, **Bayou Choctaw** caverns **18 and 20**, **Bryan Mound** caverns **2 and 5**, and the **ten** Big Hill wells. The cavern tests at these sites will also use a data collection system similar to that shown in Figure 8A in an attempt to eliminate the problems encountered on WH 11 early in the test.

We plan to continue analyses of the pressure data collected by the **O & M** contractor as part of the effort to quantify the primary variables in salt cavern creep closure. We also plan to run temperature logs in Big Hill wells to obtain a formation temperature profile and will evaluate temperature logs in caverns to obtain oil temperature profiles.

An active program is underway at Sandia to construct a cavern temperature model and to verify this model using cavern temperature logs as they become available. Another program is underway to construct a cavern behavior model that will use the temperature model in predicting cavern closure. This modeling effort will use the results of the creep test program and the analyses of the pressure data as inputs for model finalization and verification.

Conclusions and Recommendations

The conclusions reached from the data are:

1. This test method provides usable data for mathematical model comparison. and for baseline data to be used in the long-term monitor program.
2. The cavern mathematical models are in reasonable agreement with the field pressure data but additional development effort is required to improve temperature and closure predictions.

3. **Efforts should** continue to improve the data collection instrumentation and **data should be collected from** additional **caverns, wells, and sites.**
4. **Recommended caverns and wells to be tested are BC 18, BC 20, BM 2, BM 5, SM 6, and** all ten **BH** wells.
5. Accurate temperature **logs** should be run to provide better definition of the cavern temperature change over several 6-month time periods. In particular, thermal logs should **be** performed for caverns **which have not** recently **been** measured.

References

1. **Gulf Interstate Engineering Co., Houston, TX, “Certificates of Usability and Integrity for the SPR Program West Hackberry Site”, November 8, 1977.**
2. **Louis Records and Associates Inc., “Well History for Workover of West Hackberry Well 11”, April 1979.**
3. **Louis Records and Associates Inc., “Well History for Reentry Well 11A at West Hackberry”, December 1978.**
4. **Louis Records and Associates Inc., “Well History for Reentry Well 11B at West Hackberry”. March 1979.**
5. **3. F. Ney and H. M. Stoller. “Systems Integration and Engineering Support Study for the SPR Program”, SAND79-0637, June 1979.**
6. **Williams-Fenix and Sisson, “Well History for Well 112 at West Hackberry”. July 13, 1981.**
7. **G. H. Whiting, Woodward-Clyde Consultants, R. R. Beasley, “SPR Geological Site Characterization Report West Hackberry Salt Dome”. SAND80-7131, October 1980.**
8. **R. R. Beasley, “SPR Oil Storage Cavern Sulphur Mines 6 Certification Tests and Analysis”. SAND81-2068. April 1982.**
9. **R. R. Beasley, “SPR Oil Storage Cavern Sulphur Mines 7 Certification Tests and Analysis”, SAND81-2069, May 1982.**
10. **R. R. Beasley, “SPR Oil Storage Cavern Sulphur Mines 2-4-S Certification Tests and Analysis”, SAND81-2070, October 1982.**
11. **K. L. Coin, “Interim Report of Recertification Program for West Hackberry Cavern 6”. SAND80-2875, September 1981.**
12. **Memo from J. F. Ney to E. E. Chapple, “Well and Cavern Leak Test Results of BC Cavern 20”, SL-SPR-EE-BC-09, May 20, 1981.**

13. **K. L. Coin**, “**SPR Oil Storage Cavern West Hackberry 6 Recertification Tests and Analysis**”, **SAND82-0543**, **March 1982**.
14. **Memo from J. F. Ney to E. E. Chapple**, “**Field Test of a Proposed Cavern Certification Test Procedure**”, **SL-SPR-EE-BC-11**, **April 7. 1982**.
15. **D. S. Preece and J. T. Foley, Jr.**, “**Long-Term Performance Prediction for SPR Salt Caverns**”, **SAND83-2343**, to be published.
16. **D. Tomasko**, “**SPR Thermal Measurement Report**”, in preparation.
17. **D. S. Preece and C. M. Stone**, “**Use of Laboratory Triaxial Creep Data and Finite Element Analysis to Predict Observed Creep Behavior of Leached Salt Caverns**”, **SAND82-0678**, **August 1982**.

Table 1.
Description of Wells

Well #	Activity Type	Date	Ref.	Top of Salt (ft)	Production Casina
11	Completion	1962	1	- -	
11	Workover	2 - 2 5 - 7 9	2	2056	9 5/8-36 lb/ft -2790'
11A	Re-entry	1 1-4-78	3	2100	13 3/8 - 61 lb/ft -2874'
11B	Re-entry	1-9-79	4	2100	13 3/8 - 54.5 & 61 lb/ft -2890'
112	Completion	2-27-81	6	2041	20- 94 & 106.5 & 133 lb/ft -2463'

Table 2.
Cavern and Well Parameters

Well	Total Elasticity (bbl/psi)	(A) Typical Pressure Rise (psi/day)	Closure (bbl/day)
SM6	21.5	1.0	----
SM7	20.5	0.7	---
SM 2-4-S	70	0.0	---
WH6	57	0.2 (Ref 13)	---
BC 20	21.6	---	---
WH 11	49	1.5	60(B)
WH 112	.007	3.7	0.02

A. The pressure rise is a function of cavern pressure and all data are NOT at the same conditions.

B. Includes thermal expansion.

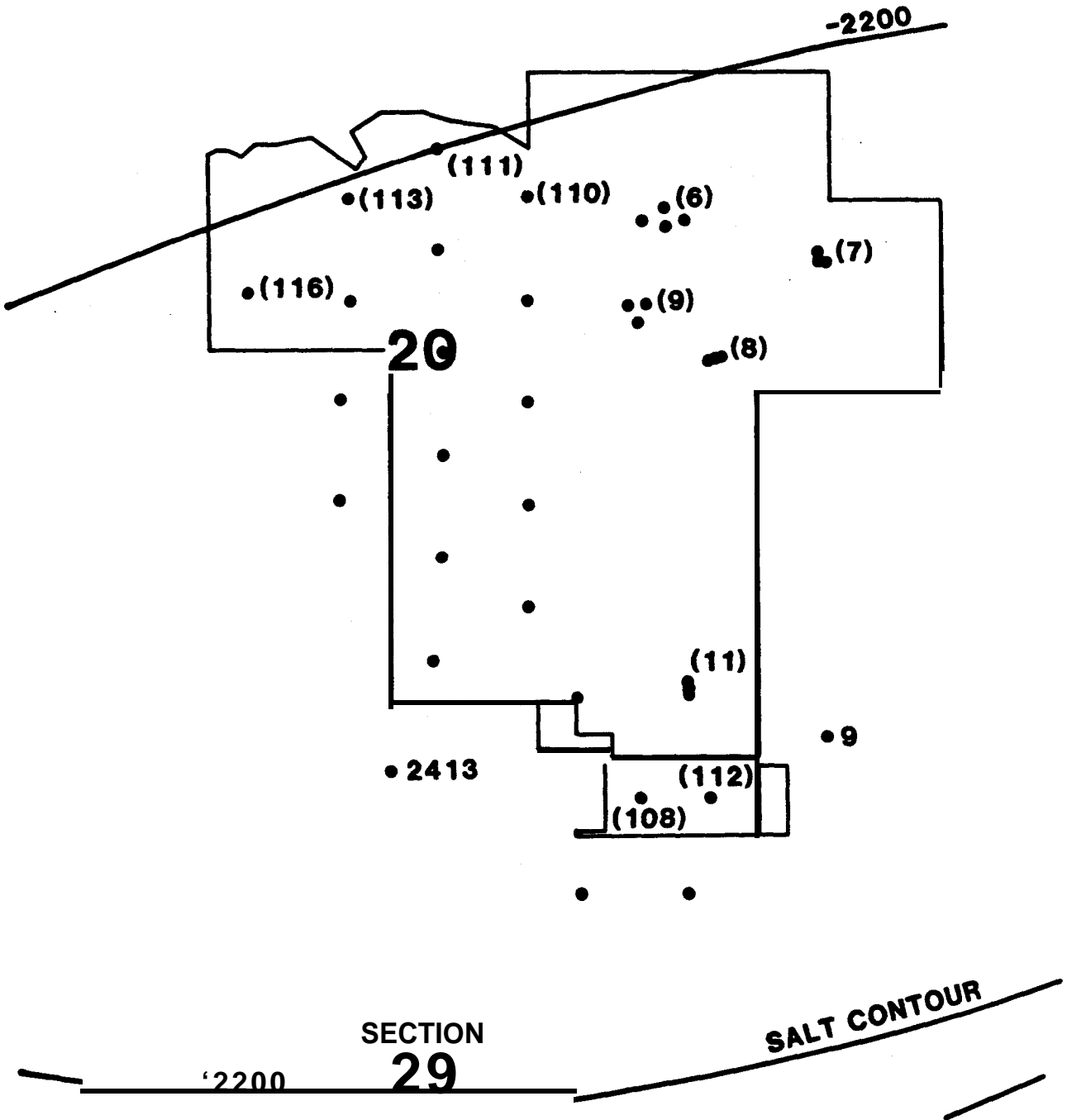


Figure 1. West Hackberry Site Layout.

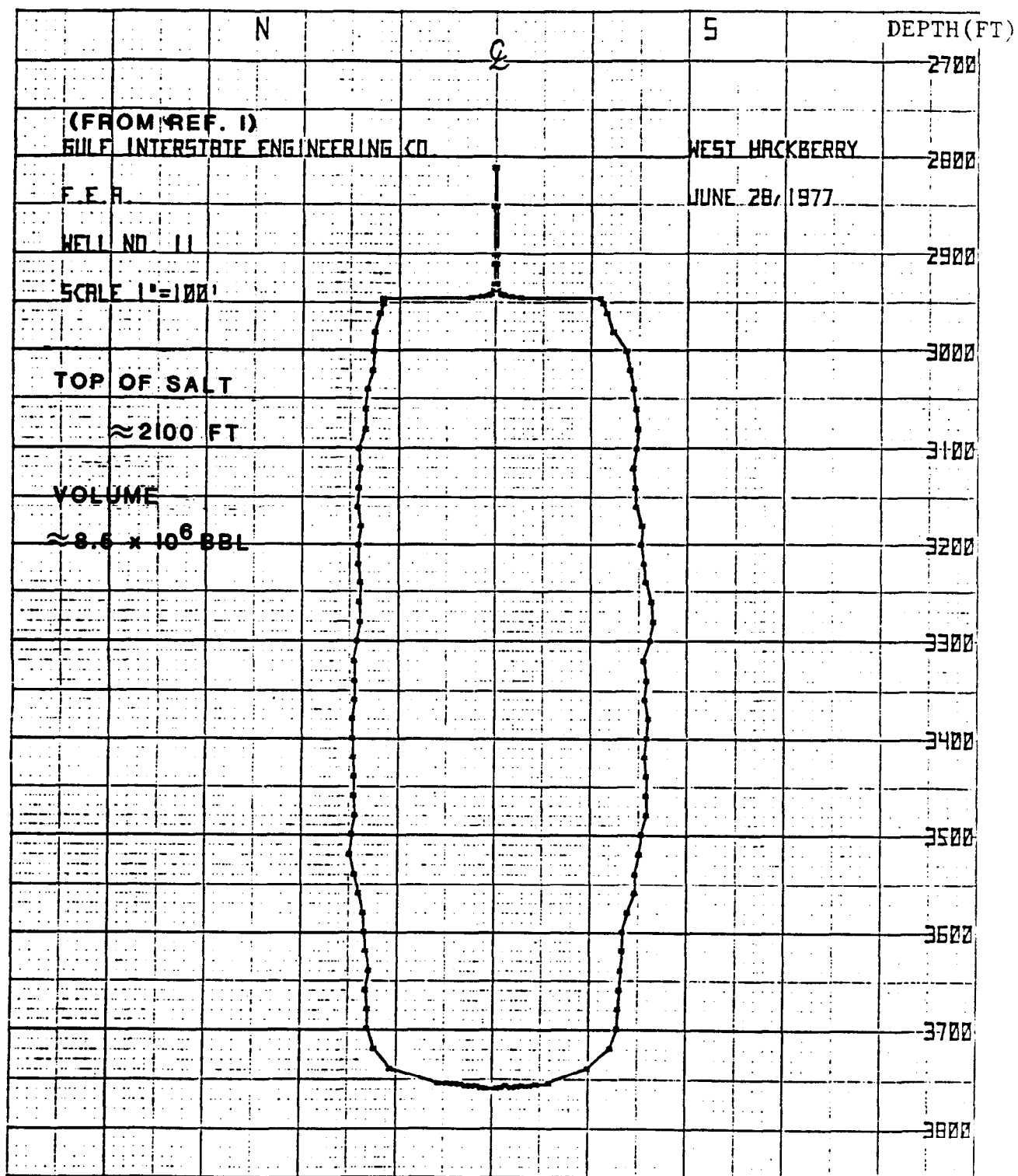


FIGURE 2. WH 11 SHAPE

WELL NAME Cavern Well #11 CAVERN Cavern #11 FIELD West Hackberry
 SERIAL NUMBER _____ TWN. _____ RGE. _____ SECTION _____
 PARISH (COUNTY) Cameron STATE La SPUD DATE _____ COMPLETION DATE 2-19-79

SURFACE

CONDUCTOR PIPE:

SIZE _____" DEPTH _____ GRADE _____
 WT. _____#/ft., COUPLING TYPE _____
 REMARKS _____

SURFACE CASING:

SIZE 20" DEPTH 1563' GRADE _____
 WT. _____#/ft., COUPLING TYPE _____
 OPEN HOLE SIZE _____
 CALIPERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH _____
 TOTAL SACKS CEMENT USED _____
 SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 REMARKS _____

PROTECTION CASING:

SIZE 13 3/8" DEPTH 2808' GRADE _____
 WT. _____#/ft., COUPLING TYPE _____
 OPEN HOLE SIZE _____
 CALIPERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH _____
 TOTAL SACKS CEMENT USED _____
 SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 REMARKS _____

PRODUCTION CASING:

SIZE 9 5/8" DEPTH 2790' GRADE _____
 WT. 26 #/ft., COUPLING TYPE _____
 OPEN HOLE SIZE _____
 CALIPERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH _____
 TOTAL SACKS CEMENT USED _____
 SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 REMARKS _____

FORMATION DATA

TOP OF CAPROCK 1529'
 TOP OF SALT 2056'
 TOP OF CAVERN 2950'
 BOTTOM OF CAVERN 3780'

LOG DATA

SERVICE	DATE	LOGGED DEPTH (FEET)
_____	_____	_____
_____	_____	_____
_____	_____	_____

CORE DATA

DEPTH CORED	From - To (ft)
_____	_____ to _____
_____	_____ to _____
_____	_____ to _____
_____	_____ to _____

DIAMETER OF CORE (Inches)

FORMATION TYPE

REMARKS

LOUIS RECORDS AND ASSOCIATES, INC.
 LAFAYETTE, LA
 Cavern Well #11

SCHEMATIC
 DATE 2-25-79 BY MJS

FIGURE 3. WELL II DESCRIPTION

WELL NAME Reentry 11A CAVERN 11 FIELD WEST HACKBERRY
 PERMIT NUMBER 544-78 TWN. 133 RGE. 10W SECTION 30
 PARISH (COUNTY) Cameron STATE LA. STUD DATE 8-26-78 COMPLETION DATE 11-4-78

SURFACE

CONDUCTOR PIPE:

SIZE 26" DEPTH 95' GRADE _____
 WT. 11/16" COUPLING TYPE _____
 REMARKS DRIVEN TO 113 RPP

SURFACE CASING:

SIZE 20" DEPTH 1241' GRADE K-55
 WT. 13 1/2" COUPLING TYPE STPC
 OPEN HOLE SIZE 24
 CALIPERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH 75
 TOTAL SACKS CEMENT USED 2100
1200 SACKS OF CLASS "H" - SLURRY DENSITY 11.9 P.P.G.
900 SACKS OF CLASS "H" - SLURRY DENSITY 16.1 P.P.G.
 REMARKS Used 2 centralizers

PROTECTION CASING:

SIZE 16" DEPTH 1861' GRADE K-55
 WT. 8 1/2" COUPLING TYPE STPC
 OPEN HOLE SIZE 18 1/2
 CALIPERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH 50
 TOTAL SACKS CEMENT USED 710
400 SACKS OF CLASS FLW - SLURRY DENSITY _____ P.P.G.
310 SACKS OF CLASS H - SLURRY DENSITY 16.5 P.P.G.
 REMARKS _____

PRODUCTION CASING:

SIZE 13 3/4" DEPTH 2874' GRADE K-55
 WT. 6 1/2" COUPLING TYPE STPC
 OPEN HOLE SIZE 17 1/2
 CALIPERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH 50
 TOTAL SACKS CEMENT USED 1075
150 SACKS OF CLASS FLW - SLURRY DENSITY 12.0 P.P.G.
925 SACKS OF CLASS H - SLURRY DENSITY 16.5 P.P.G.
 REMARKS _____

PRODUCTION TUBING:

SIZE 9 5/8" DEPTH 3607' GRADE K-55
 WT. 36" COUPLING TYPE STPC
 REMARKS _____

FORMATION DATA

TOP OF CAPROCK 1620'
 TOP OF SALT 2100 (EST)
 TOP OF CAVERN 2993'
 BOTTOM OF CAVERN 3664'

SERVICE
Caliper, Directional, Dialog
Ind. Electrolg / BNC Acoustilog
Ind. Electrolg / BNC Acoustilog

LOG DATA (PARTIAL)

DATE	LOGGED DEPTH (FEET)
<u>8-31-78</u>	<u>114-1620</u>
<u>9-14-78</u>	<u>1229-2195</u>
<u>10-17-78</u>	<u>2195-2834</u>

CORE DATA

DEPTH CORED
 From - To (ft.)

_____	to	_____
_____	to	_____
_____	to	_____
_____	to	_____

DIAMETER OF CORE
 (Inches)

FORMATION TYPE

REMARKS

LOUIS RECORDS AND ASSOCIATES, INC.
 LAFAYETTE, LA

RE-ENTRY WELL NO. 11A
 SCHEMATIC
 DATE 11-16-78 BY STR

FIGURE 4. WELL 11A DESCRIPTION

RE-ENTRY WELL NO. 11-B

WELL NAME REM 11-B CAVERN 11 FIELD W. HACKBERRY
 SERIAL NUMBER 543-78 TWN. 12S RGE. 10W SECTION 20
 PARISH (COUNTY) CAMERON STATE LA. SPUD DATE 11/13/78 COMPLETION DATE 1/9/79

SURFACE

CONDUCTOR PIPE:

SIZE 26" DEPTH 91' GRADE _____
 WT. _____ #/ft. COUPLING TYPE _____
 REMARKS _____

SURFACE CASING:

SIZE 20" DEPTH 1630' GRADE K-55
 WT. 166.122 #/ft. COUPLING TYPE STCC
 OPEN HOLE SIZE 24"
 CALIBERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH 75
 TOTAL SACKS CEMENT USED 1475
750 SACKS OF CLASS M+A-2 - SLURRY DENSITY 11.9 P.P.G.
725 SACKS OF CLASS M+A-2 - SLURRY DENSITY 16.1 P.P.G.
 REMARKS 150 BRIS. CM T. RETURNS
TOP JOB - 100 STS 50/50 GYPSUM @ 14.5

(NOT REQUIRED)

PROTECTION CASING: (IF LOST CIRCULATION ENCOUNTERED):

SIZE _____" DEPTH _____' GRADE _____
 WT. _____ #/ft. COUPLING TYPE _____
 OPEN HOLE SIZE _____
 CALIBERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH _____
 TOTAL SACKS CEMENT USED _____
 _____ SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 _____ SACKS OF CLASS _____ - SLURRY DENSITY _____ P.P.G.
 REMARKS _____

PRODUCTION CASING:

SIZE 13 3/8" DEPTH 2890' GRADE K-55 & J-55
 WT. 54.611 #/ft. COUPLING TYPE STCC
 OPEN HOLE SIZE 17 1/2"
 CALIBERED HOLE VOLUME FACTOR _____
 BARRELS OF CEMENT PRE-FLUSH 30
 TOTAL SACKS CEMENT USED 1600
950 SACKS OF CLASS TW - SLURRY DENSITY 12.0 P.P.G.
650 SACKS OF CLASS M1 - SLURRY DENSITY 16.5 P.P.G.
 REMARKS GOT CONTAMINATED CEMENT RETURNS

PRODUCTION TUBING:

SIZE 9 5/8" DEPTH 3700' GRADE K-55
 WT. 26 #/ft. COUPLING TYPE STCC
 REMARKS HANGING STRING

FORMATION DATA

TOP OF CAPROCK 1620'
 TOP OF SALT ± 2100'
 TOP OF CAVERN 2959'
 BOTTOM OF CAVERN 3764'

LOG DATA

SERVICE	DATE	LOGGED DEPTH (FEET)
<u>BOREHOLE GEOMETRY/DIRECTINAL</u>	<u>11-21-78</u>	<u>1628' - 20'</u>
<u>TEL/ACQUITS/CALIBER/DIRECTINAL</u>	<u>12-15-78</u>	<u>2902' - 1649'</u>
<u>CBL</u>	<u>12-25-78</u>	<u>2972' - 1650'</u>

CORE DATA

DEPTH CORED From - To (ft.)	DIAMETER OF CORE (Inches)	FORMATION TYPE
_____ to _____	_____	_____
_____ to _____	_____	_____
_____ to _____	_____	_____
_____ to _____	_____	_____

REMARKS

LOUIS RECORDS AND ASSOCIATES, INC.
 LAFAYETTE, LA

RE-ENTRY WELL NO. 11-B
 DATE 3/14/79 BY CAB

FIGURE 5. WELL IIB DESCRIPTION

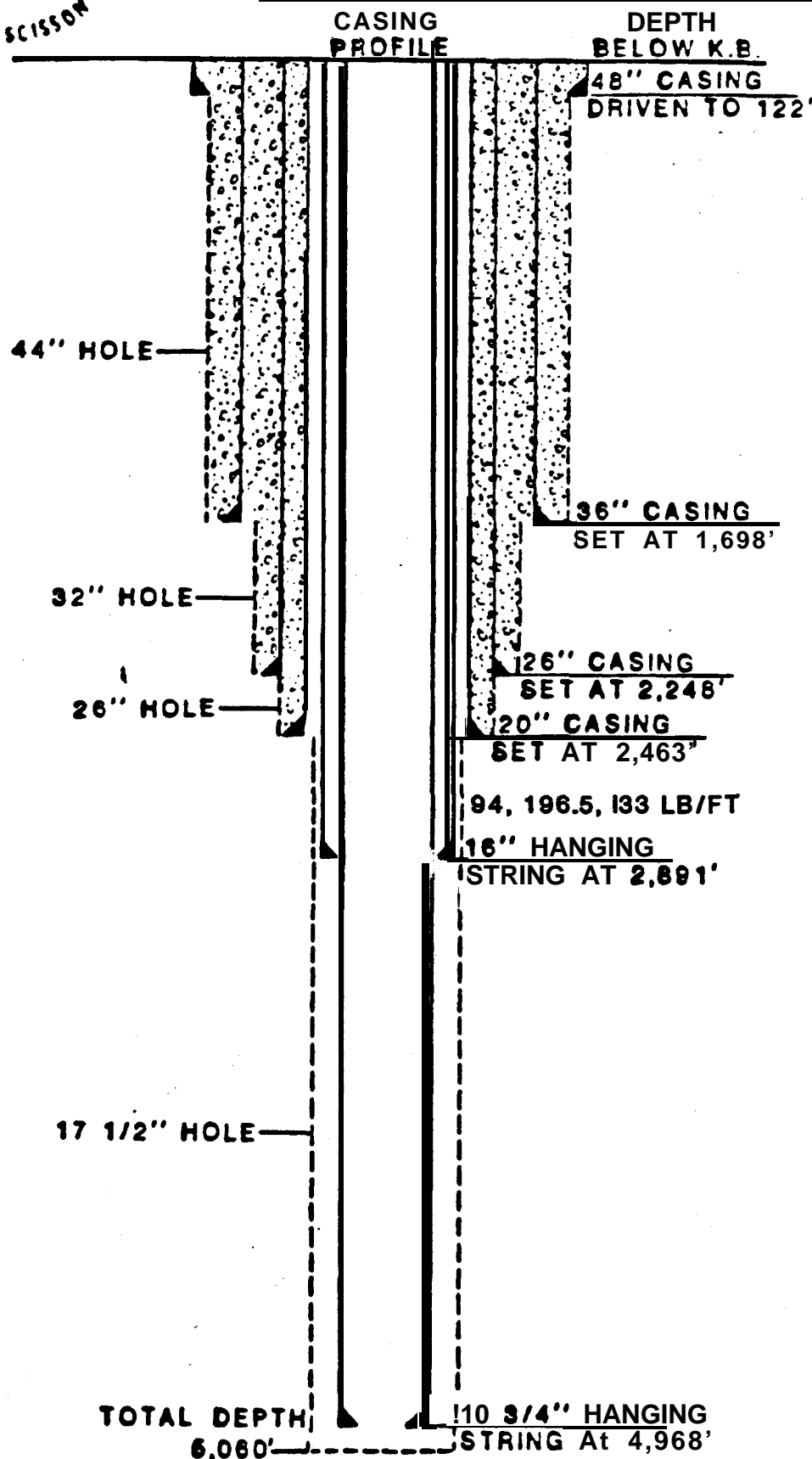


FIGURE 6. AS-BUILT CASING DIAGRAM WELL II2 WEST HACKBERRY

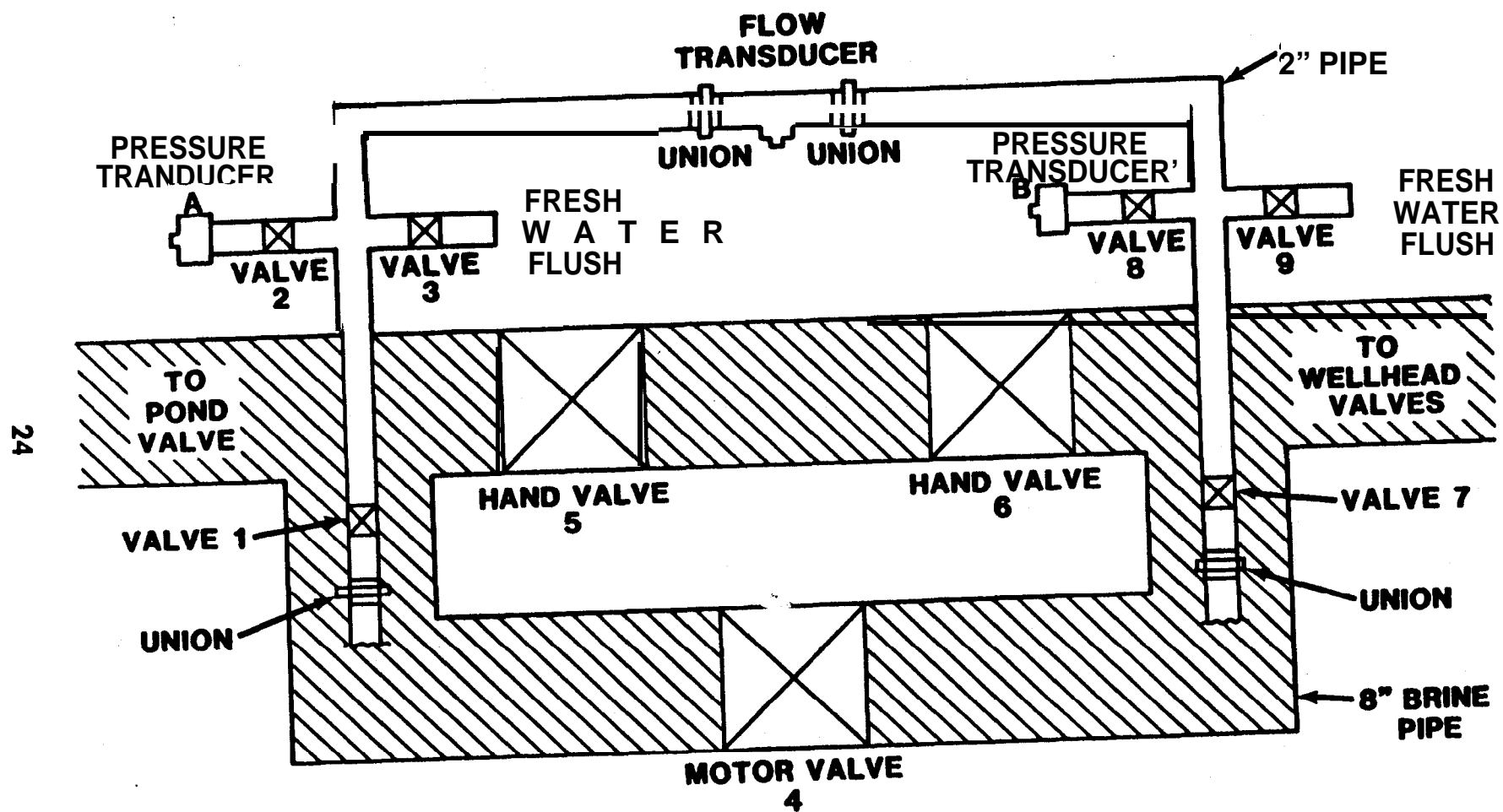


Figure 7. Pipe Diagram Creep Test - West Hackberry Cavern 11.

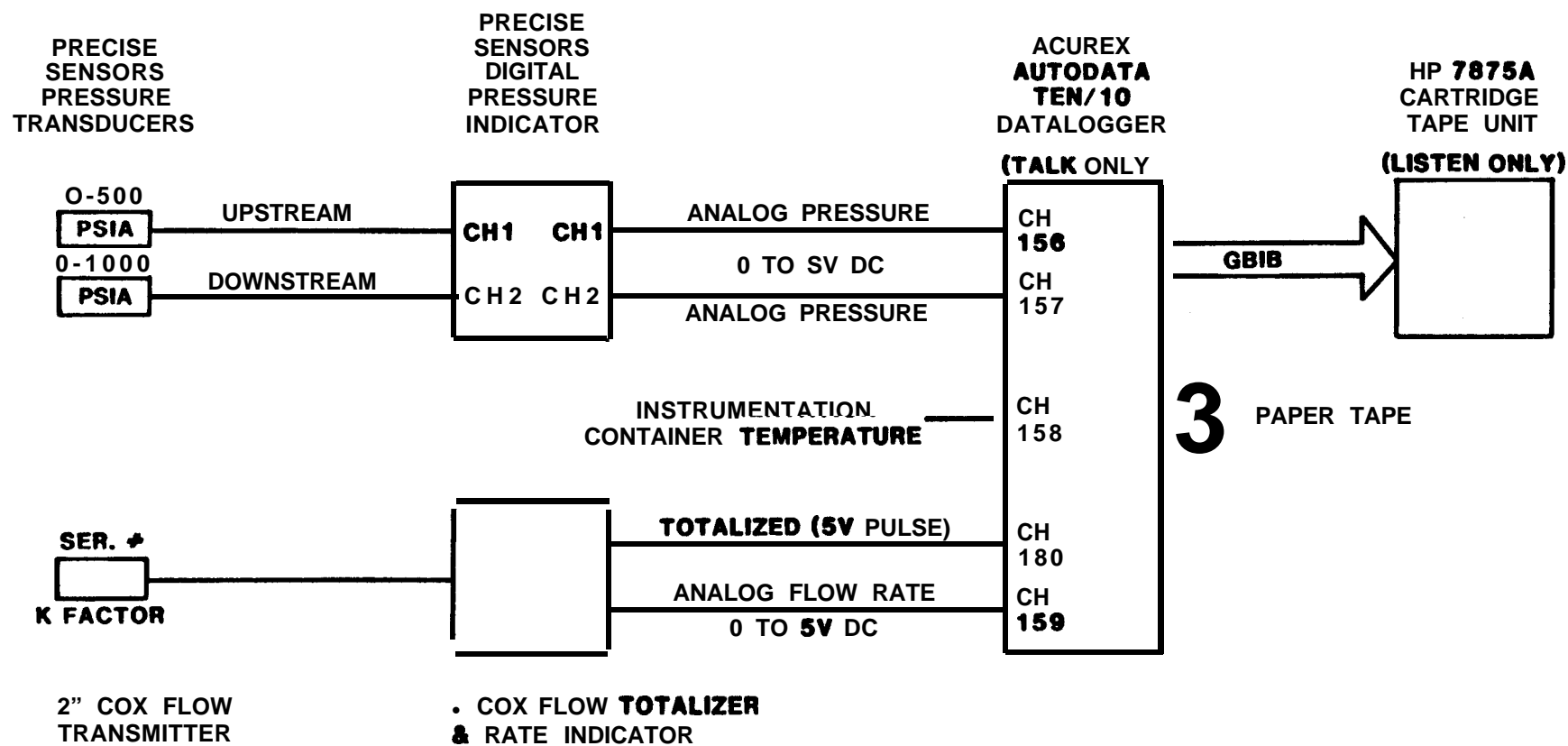


Figure 8. W.H. 11 Block Diagram Creep Test Instrumentation.

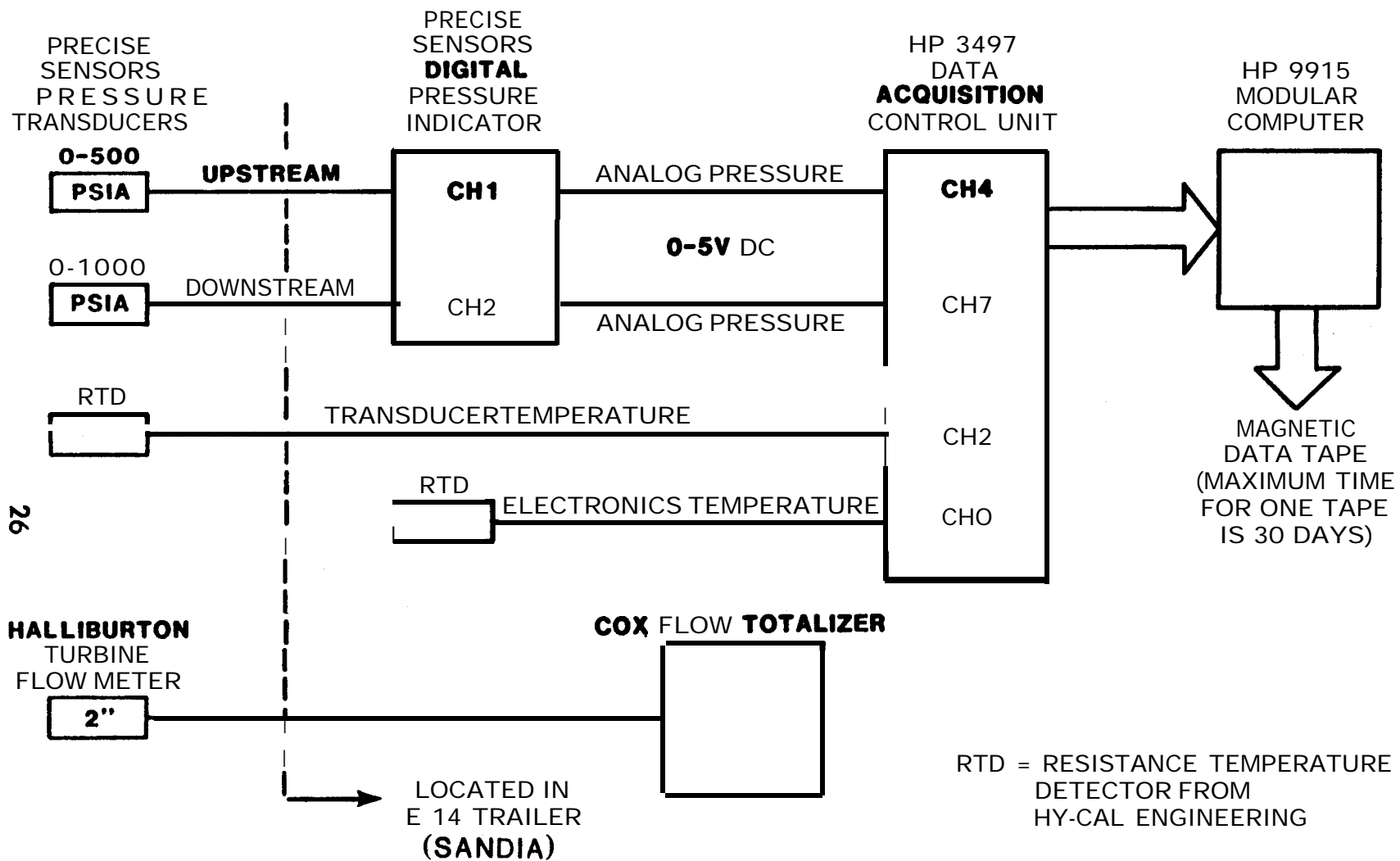


Figure 8A. W.H. 11. Block Diagram Creep **Test** Instrumentation.

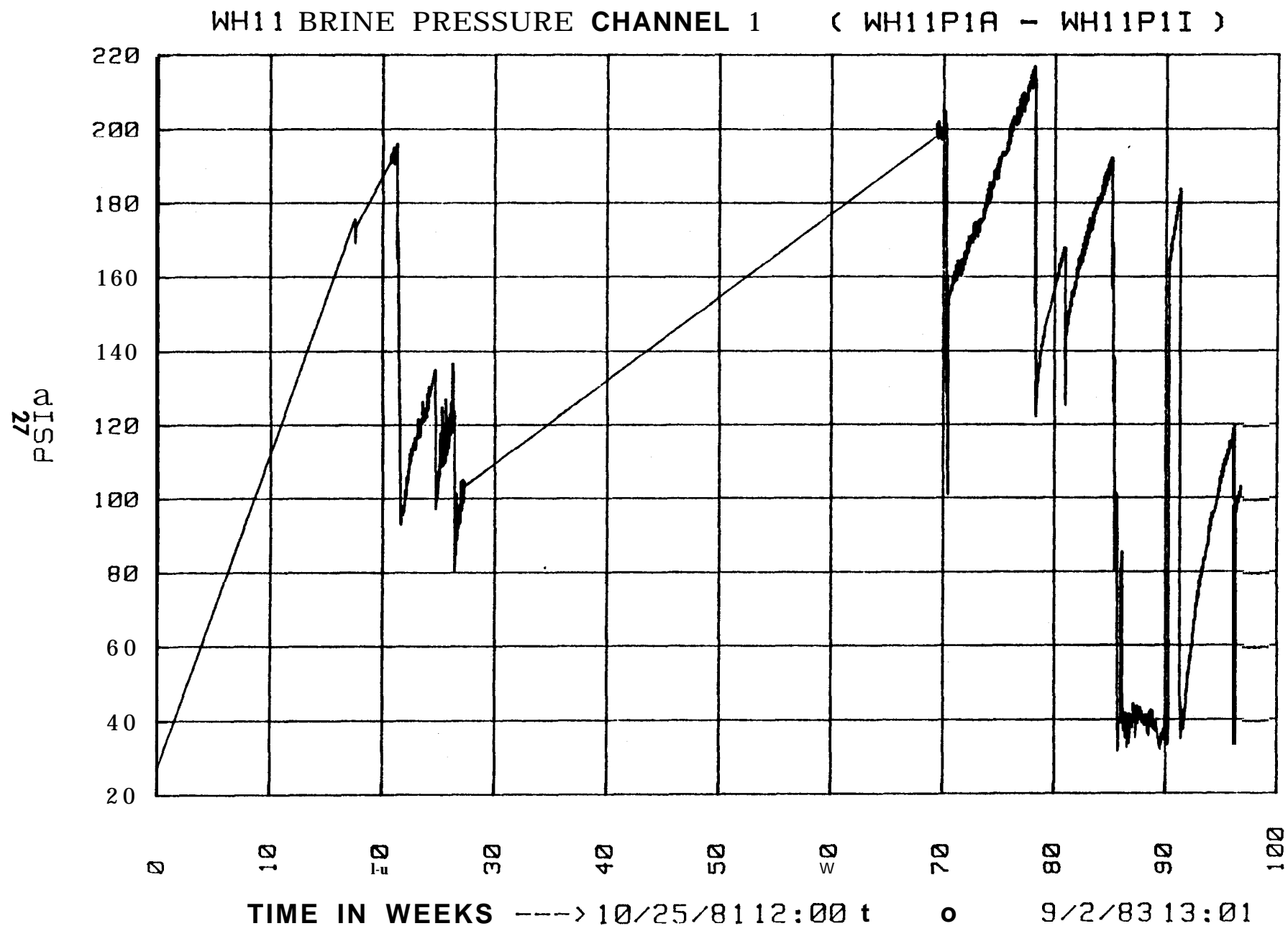


FIGURE 9. WH II BRINE PRESSURE VS TIME

WH11 BRINE PRESSURE CHANNEL 2 (WH11P2A - WH11P2I)

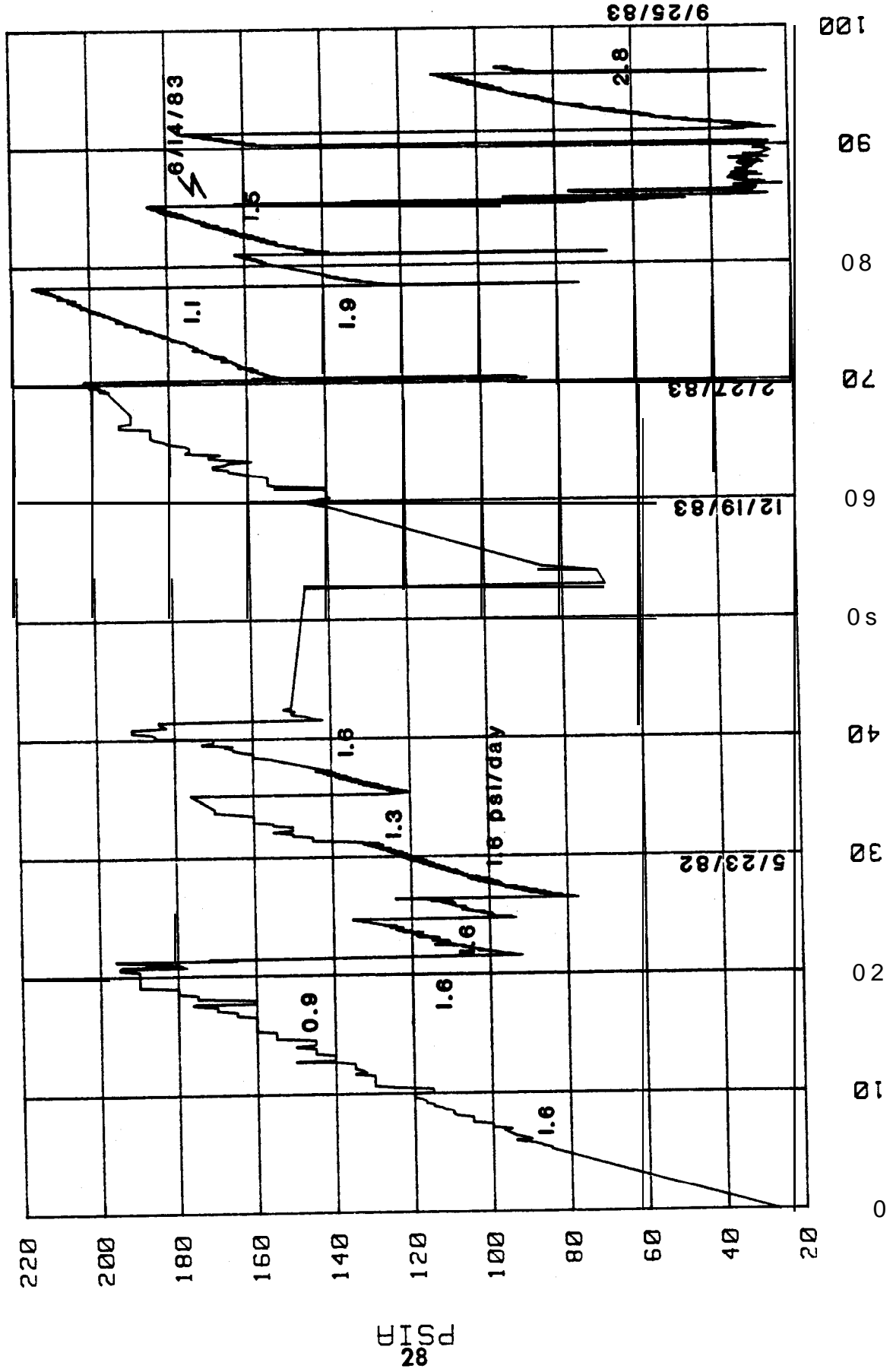
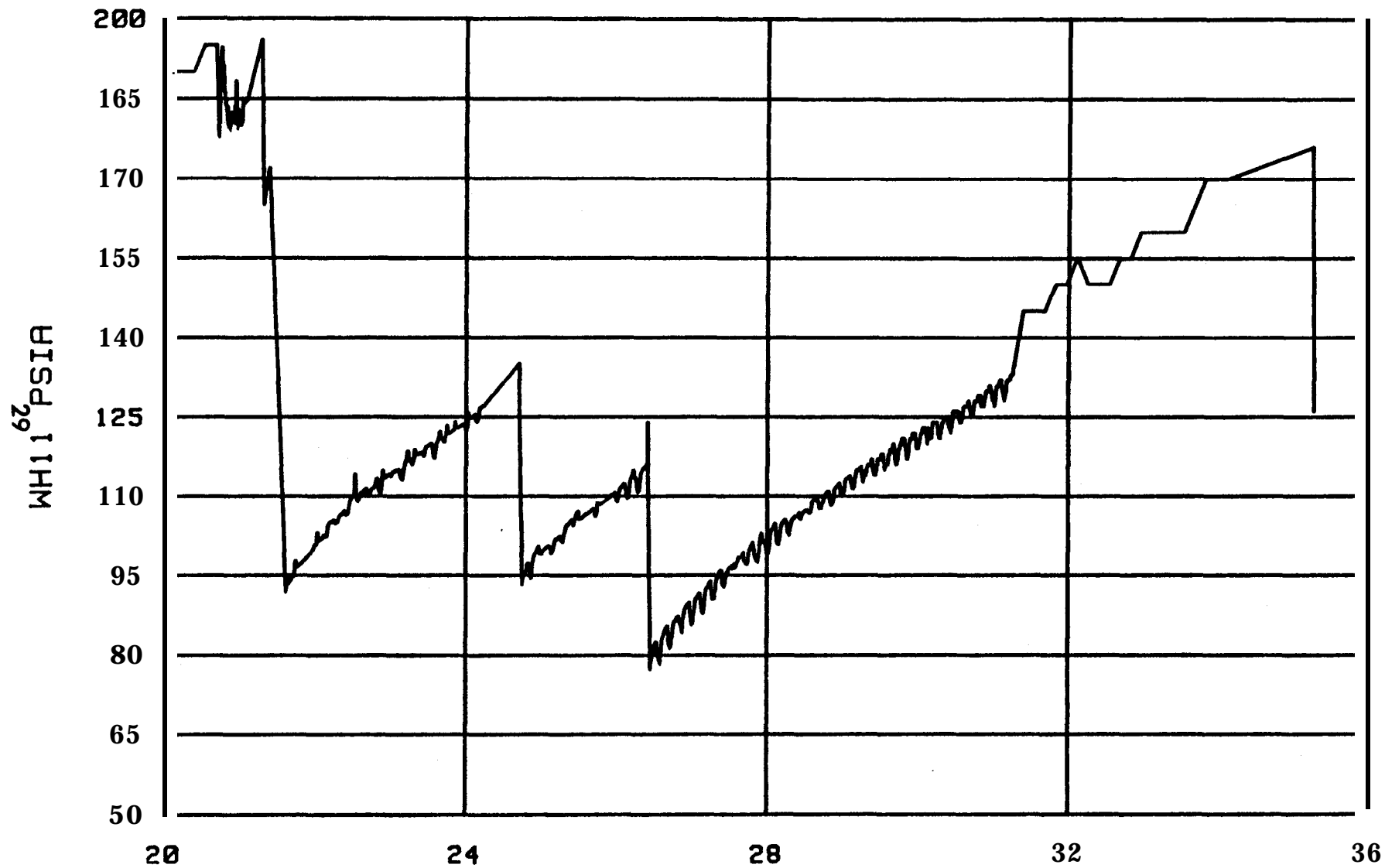
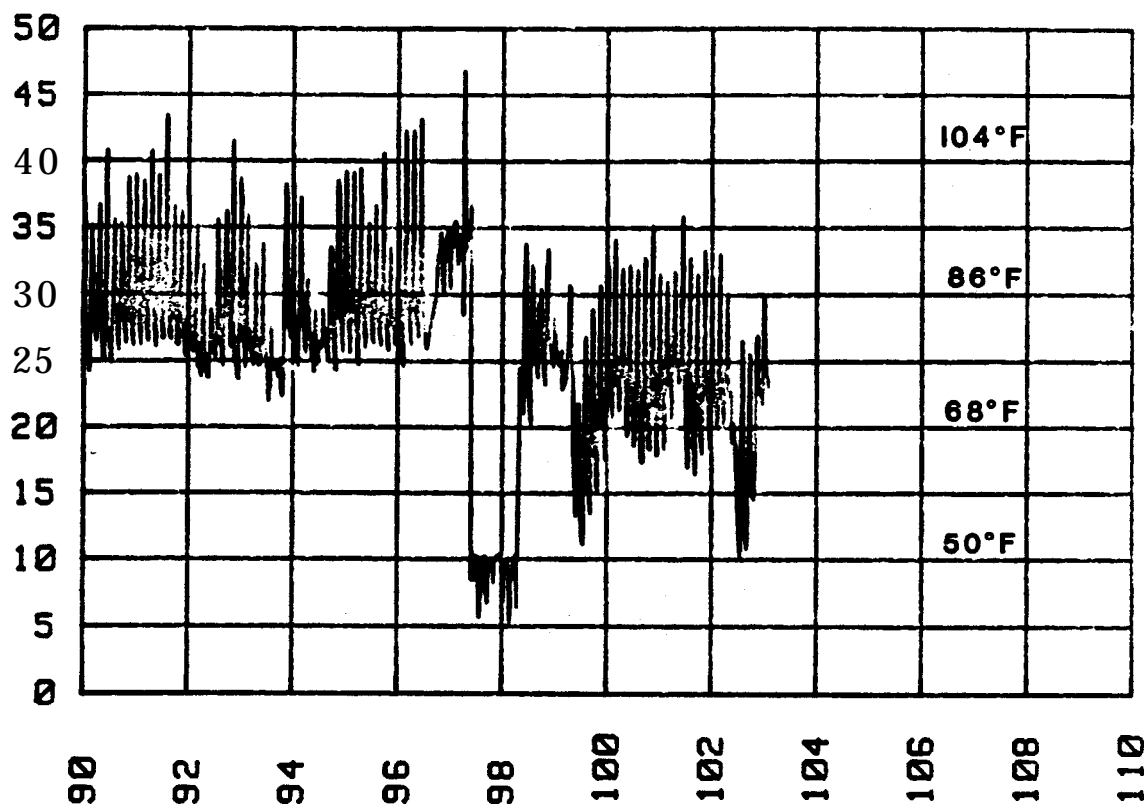


FIGURE 9A. WH 11 BRINE PRESSURE VS TIME



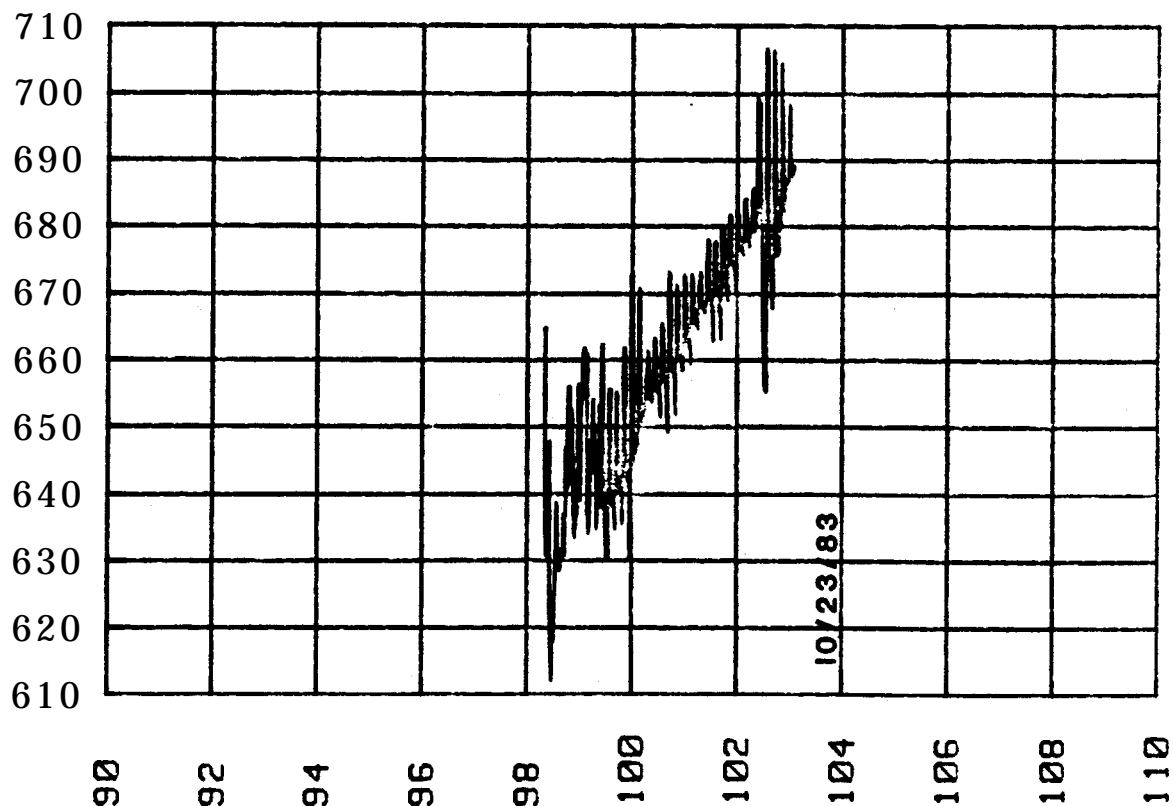
WEEKS (0=10/25/81)
FIG 9B WH11 BRINE PRESSURE VS TIME

WH11 DEG C



WEEKS FROM 07/17/83 12:00 T O 10/17/83 03:10
FIG SC WH11 TEMP. OF PRESSURE TRANSDUCER

WH11 PSI



WEEKS FROM 09/13/83 21:04 TO 10/17/83 03:10
FIG SD WH11 OIL PRESSURE VS TIME

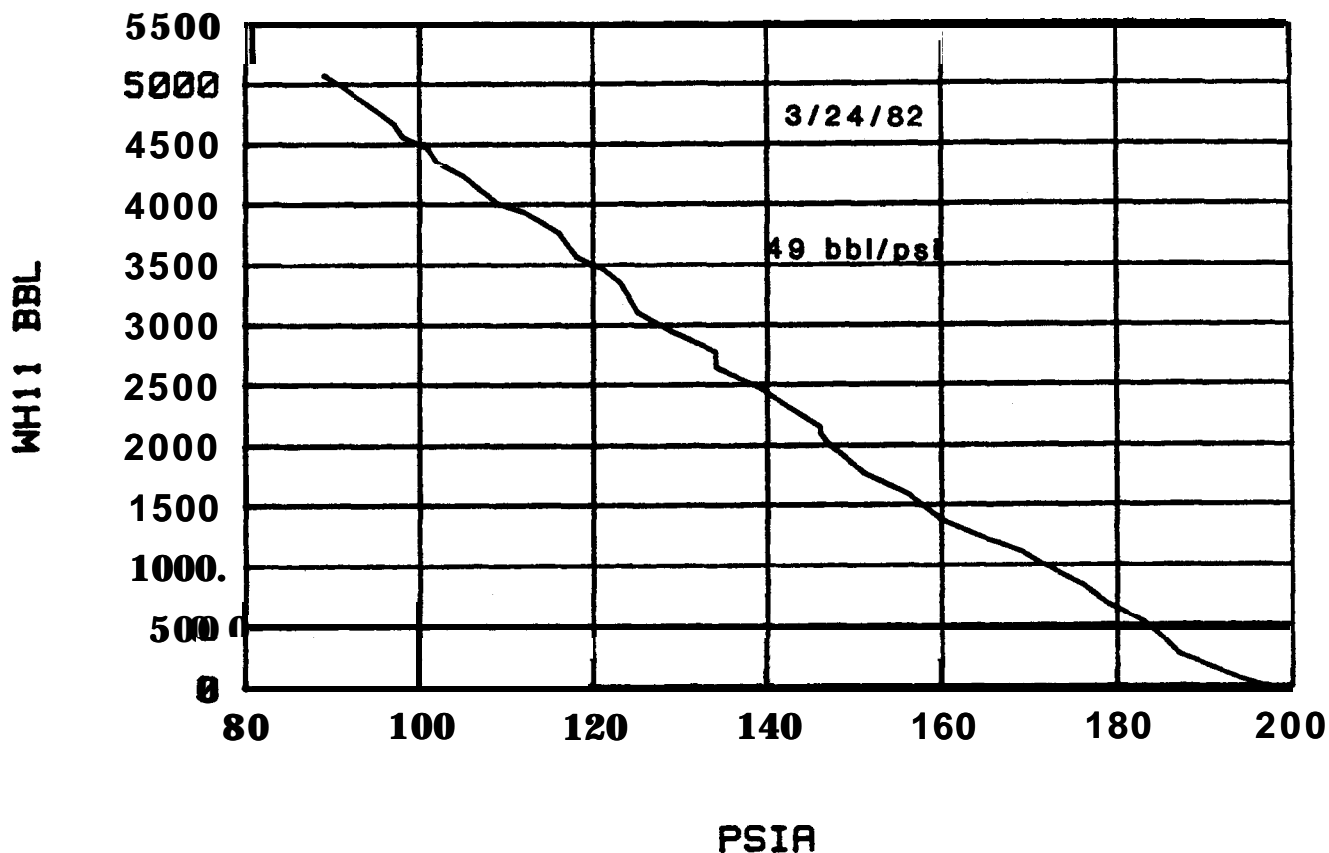


FIG 10A WH11 VOLUME REMOVED VS PRESSURE

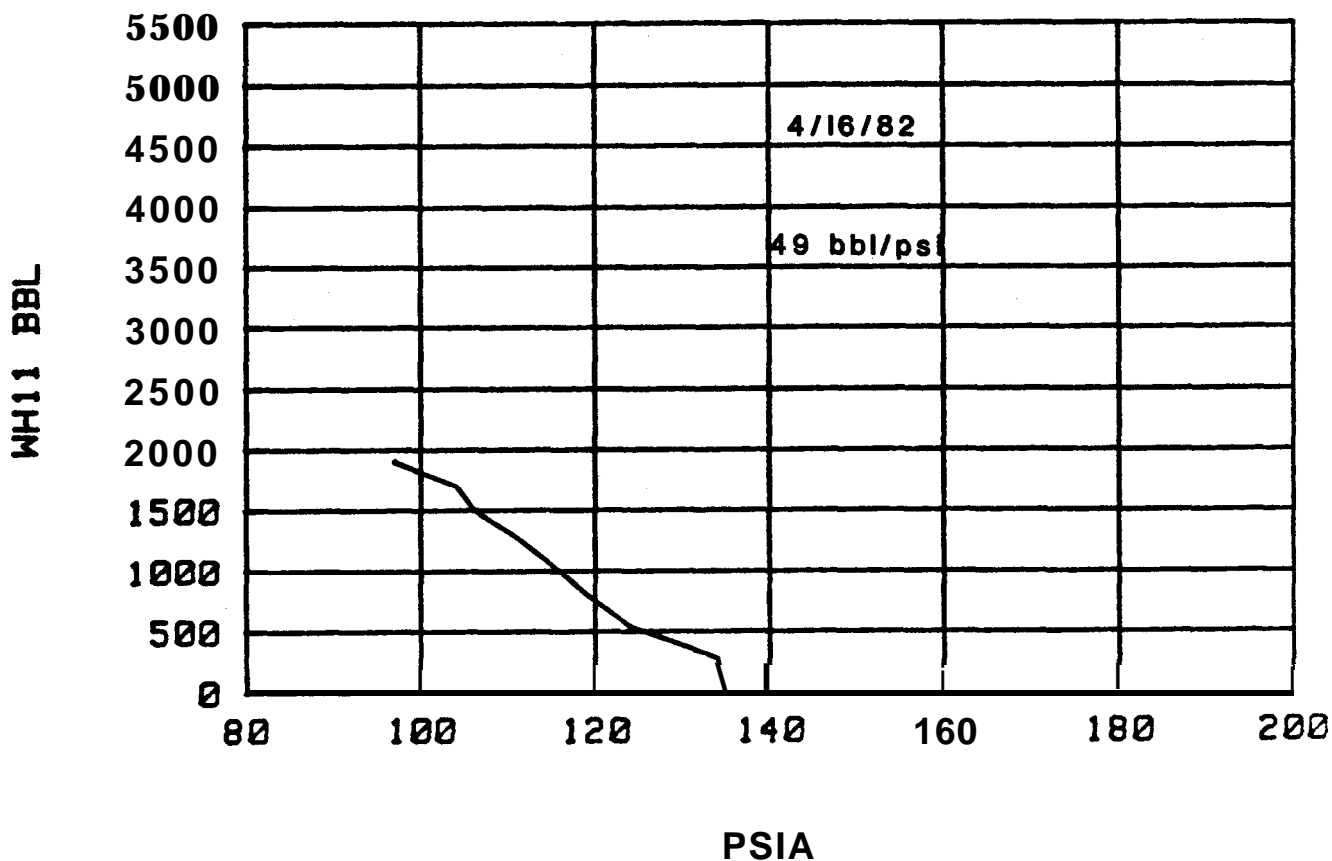
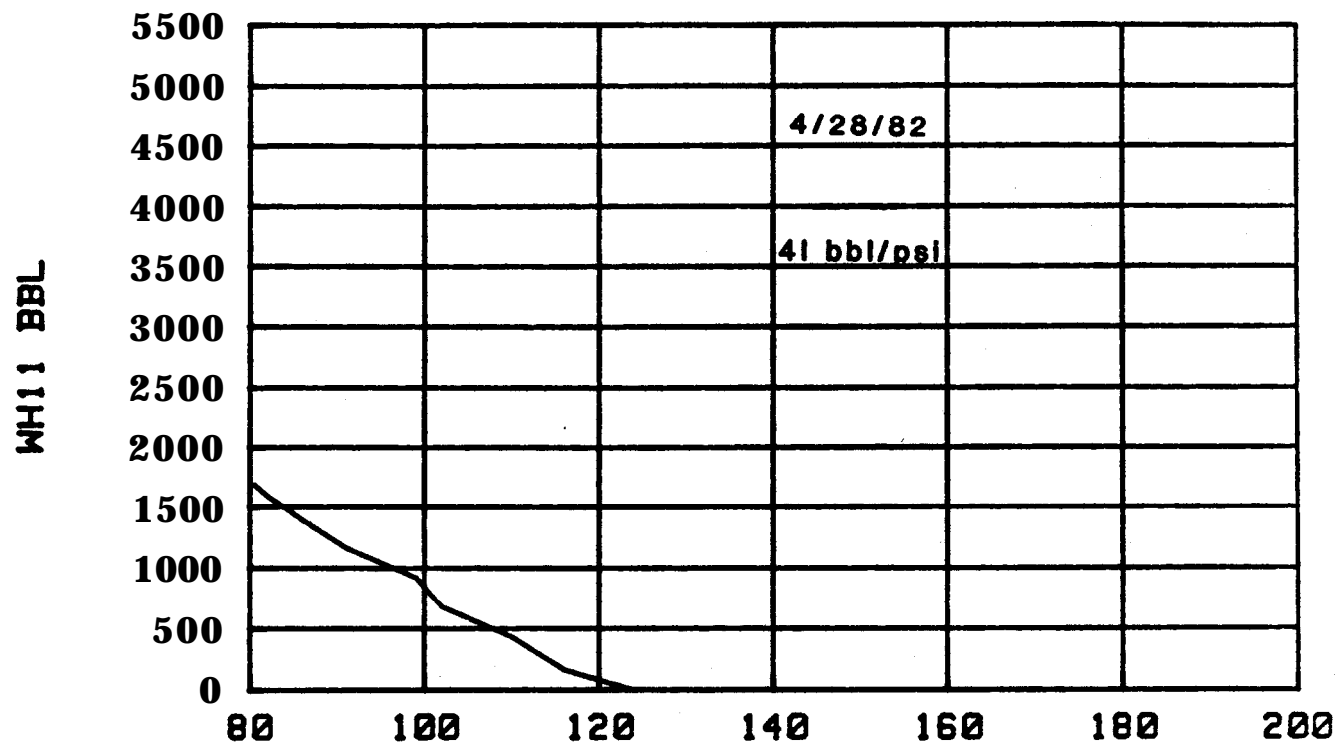
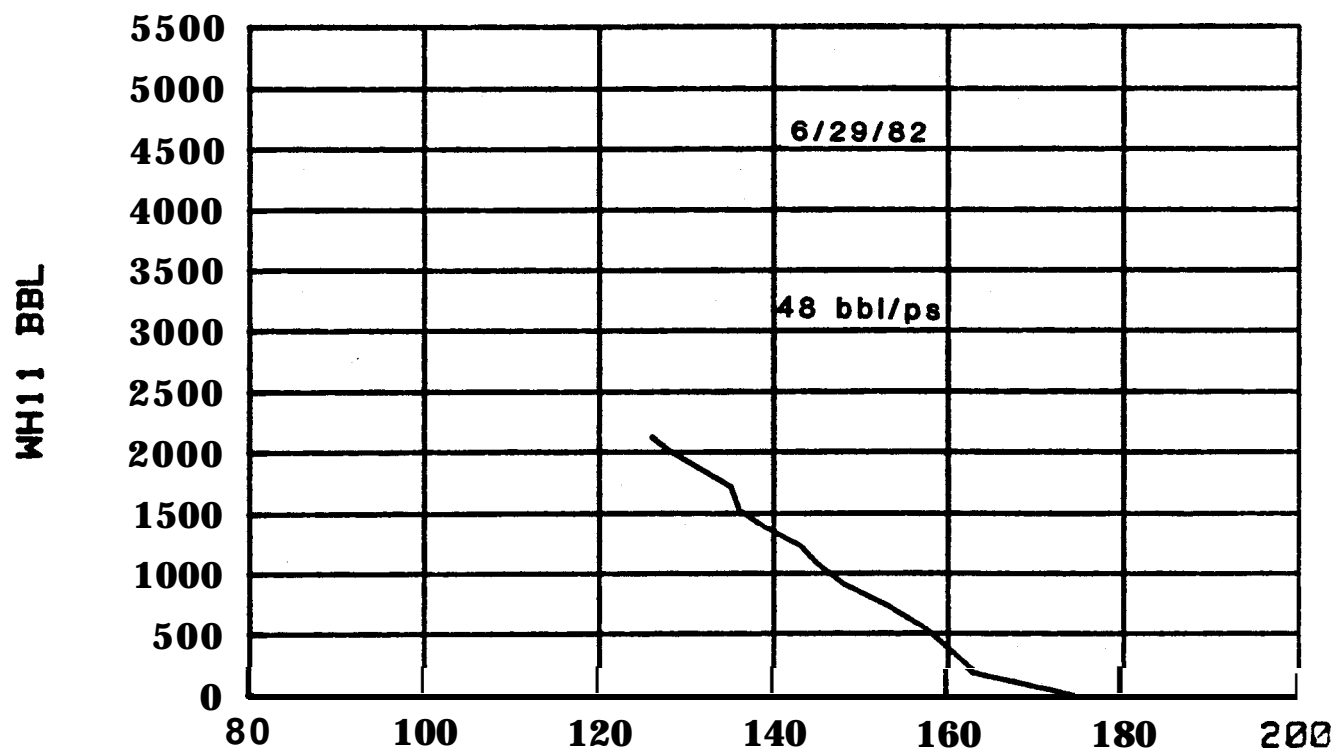


FIG 10B WH11 VOLUME REMOVED VS PRESSURE



PSIA
FIG 10C WH11 VOLUME REMOVED VS PRESSURE



PSIA
FIG 10D WH11 VOLUME REMOVED VS PRESSURE

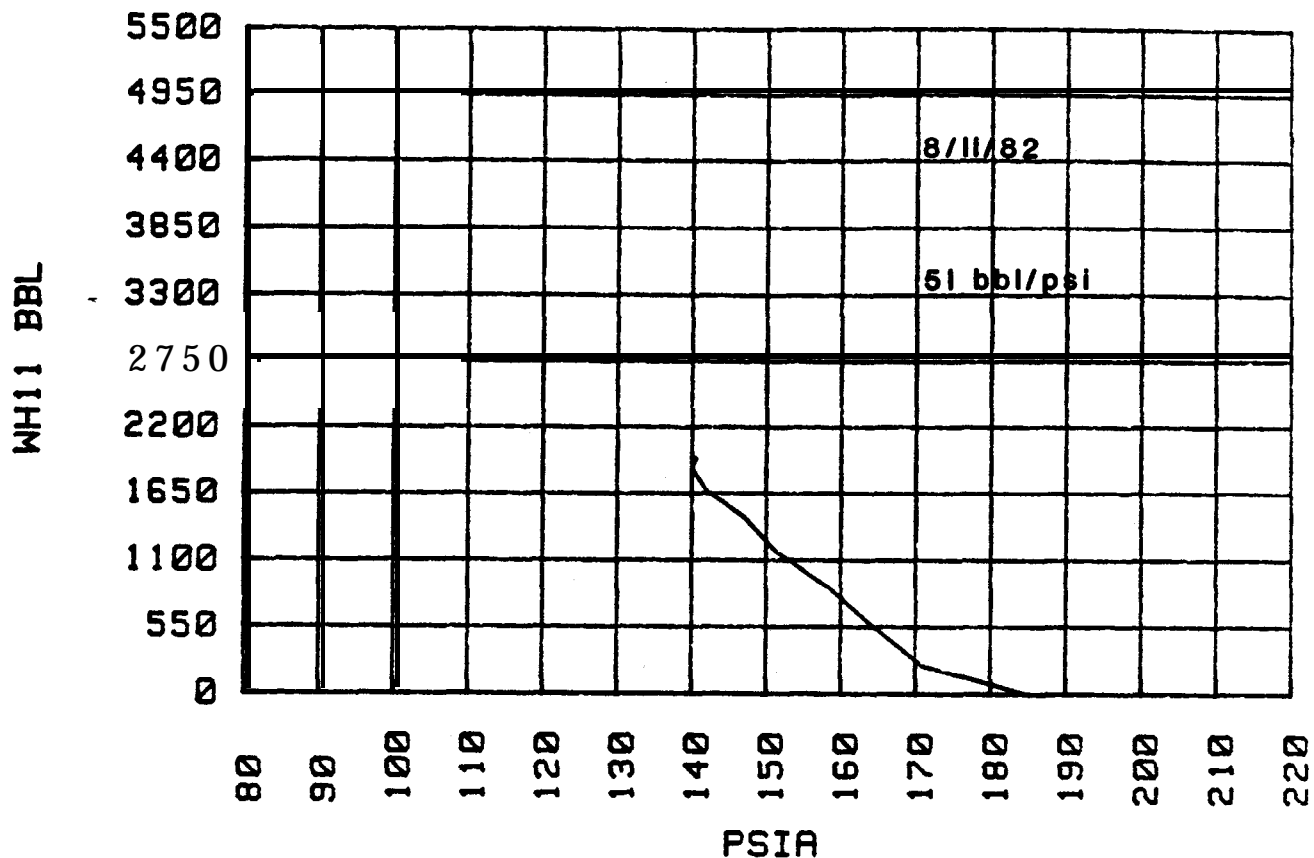


FIG 10E WH11 VOLUME REMOVED VS PRESSURE

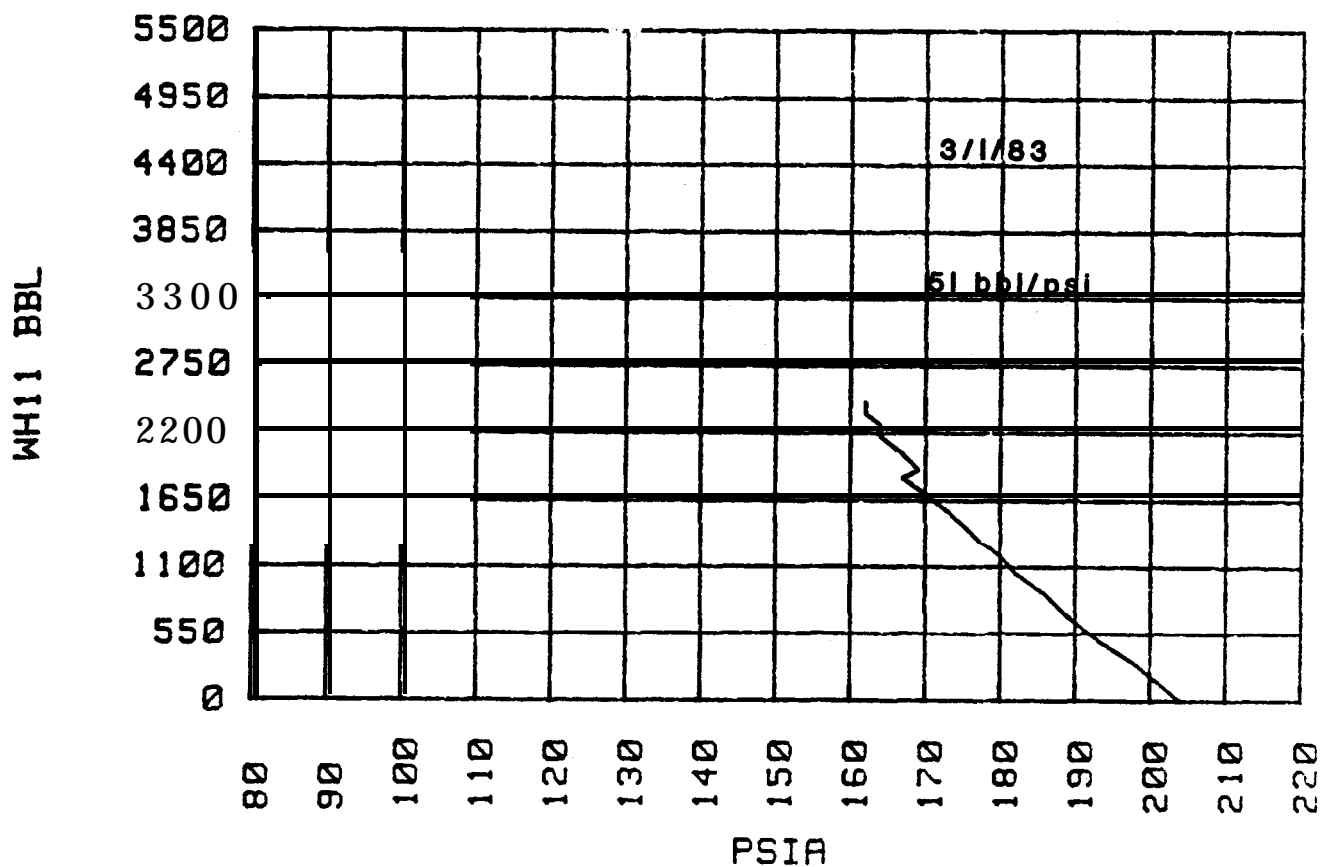


FIG 10F WH11 VOLUME REMOVED VS PRESSURE

WH11 BBL

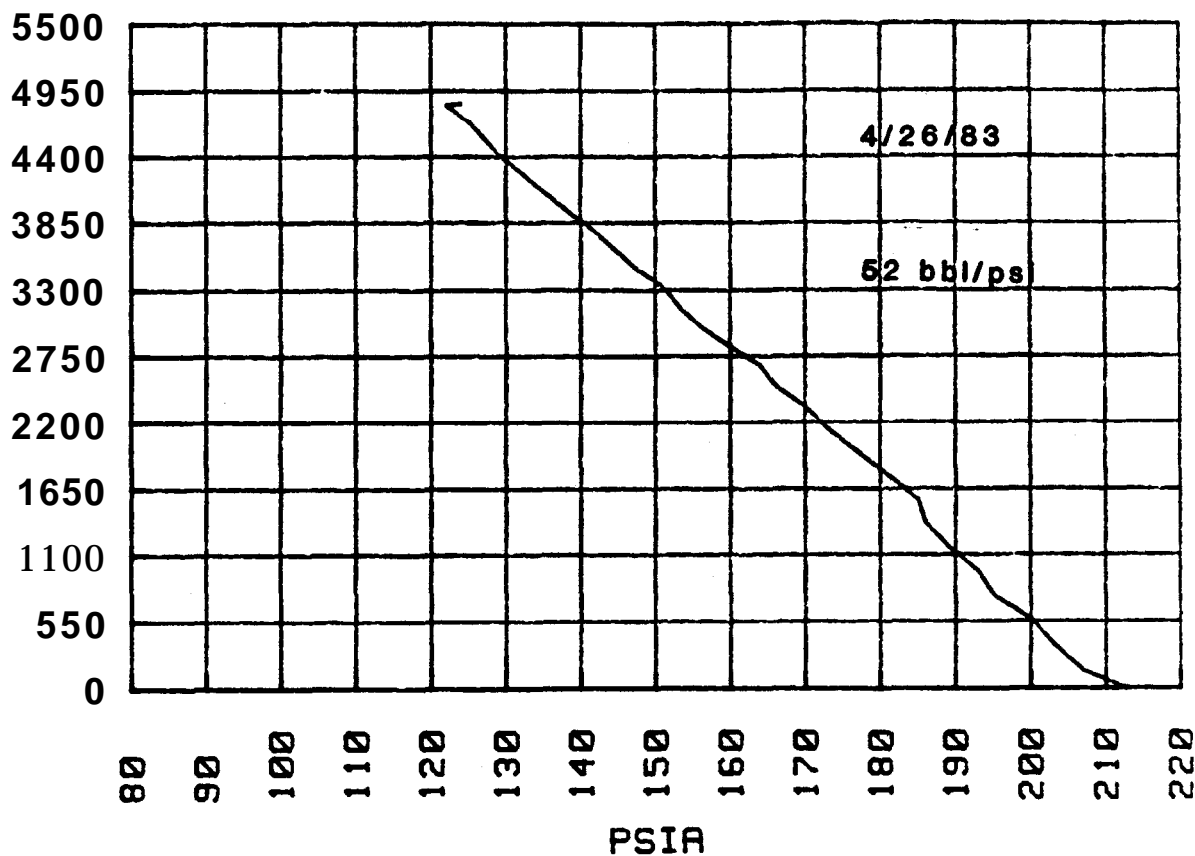


FIG 10G WH11 VOLUME REMOVED VS PRESSURE

WH11 BBL

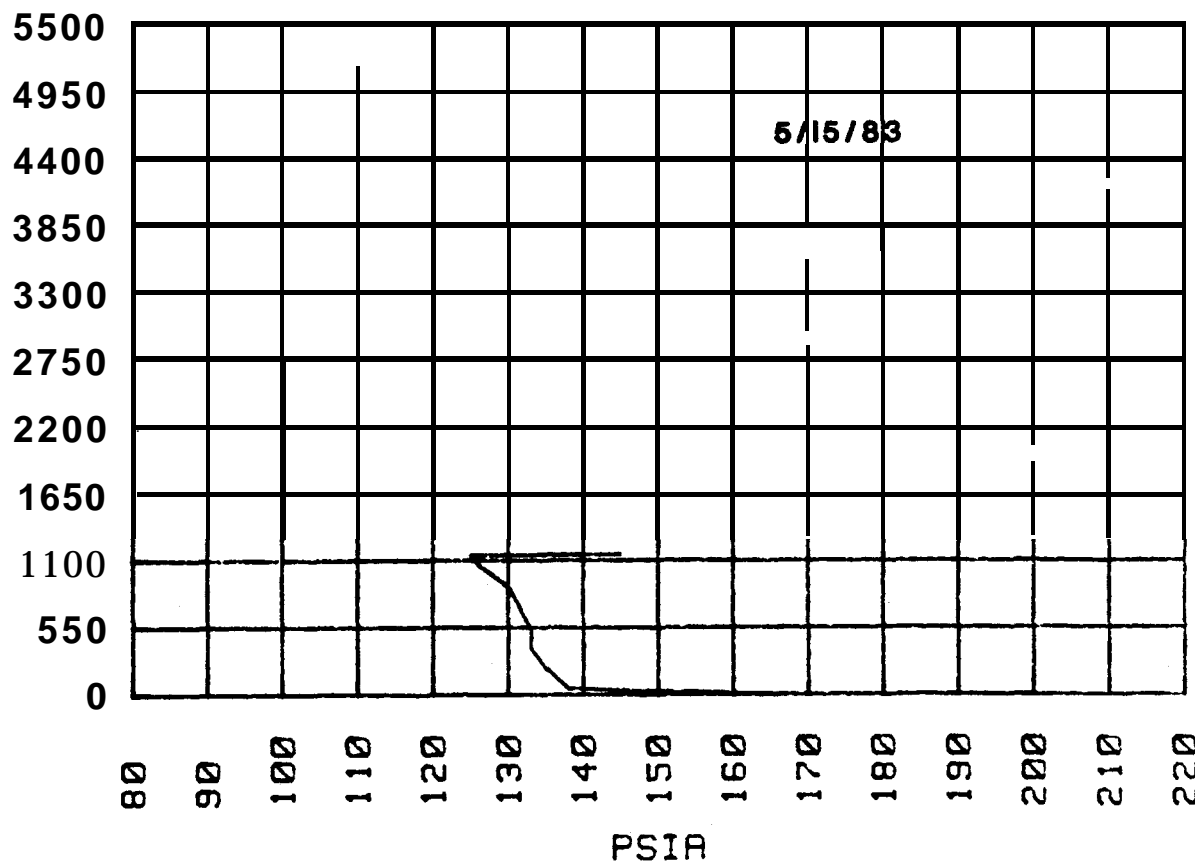


FIG 10H WH11 VOLUME REMOVED VS PRESSURE

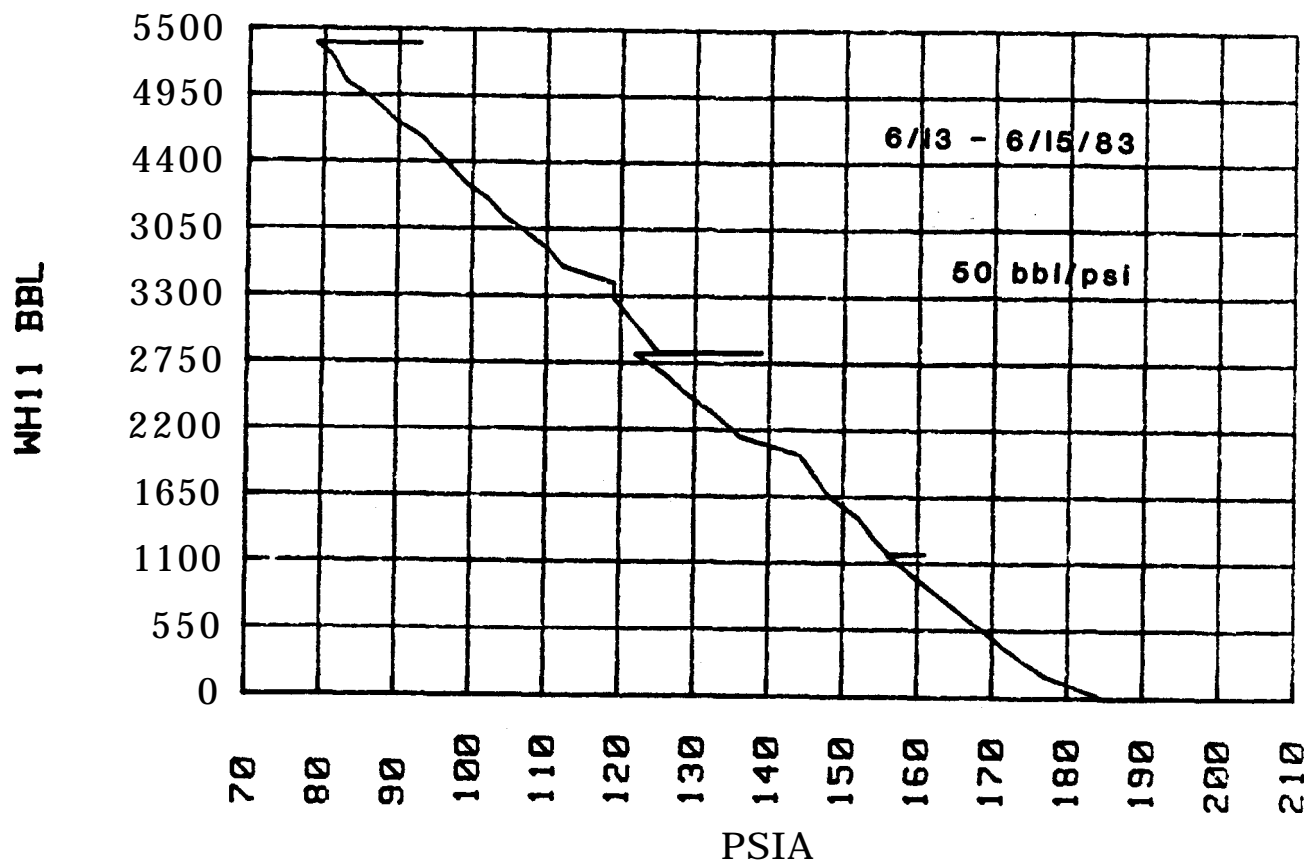


FIG 101 WH11 VOLUME REMOVED VS PRESSURE

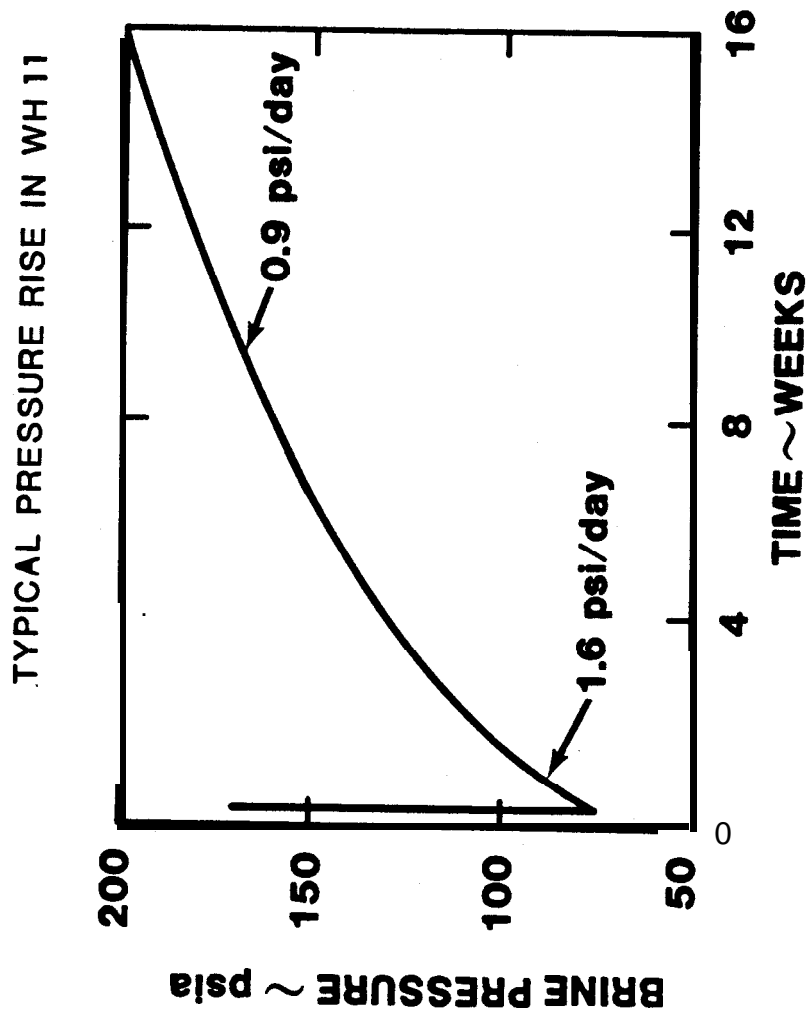


Figure 11.

TYPICAL PRESSURE CHANGE DURING BRINE REMOVAL FROM W.H. 11

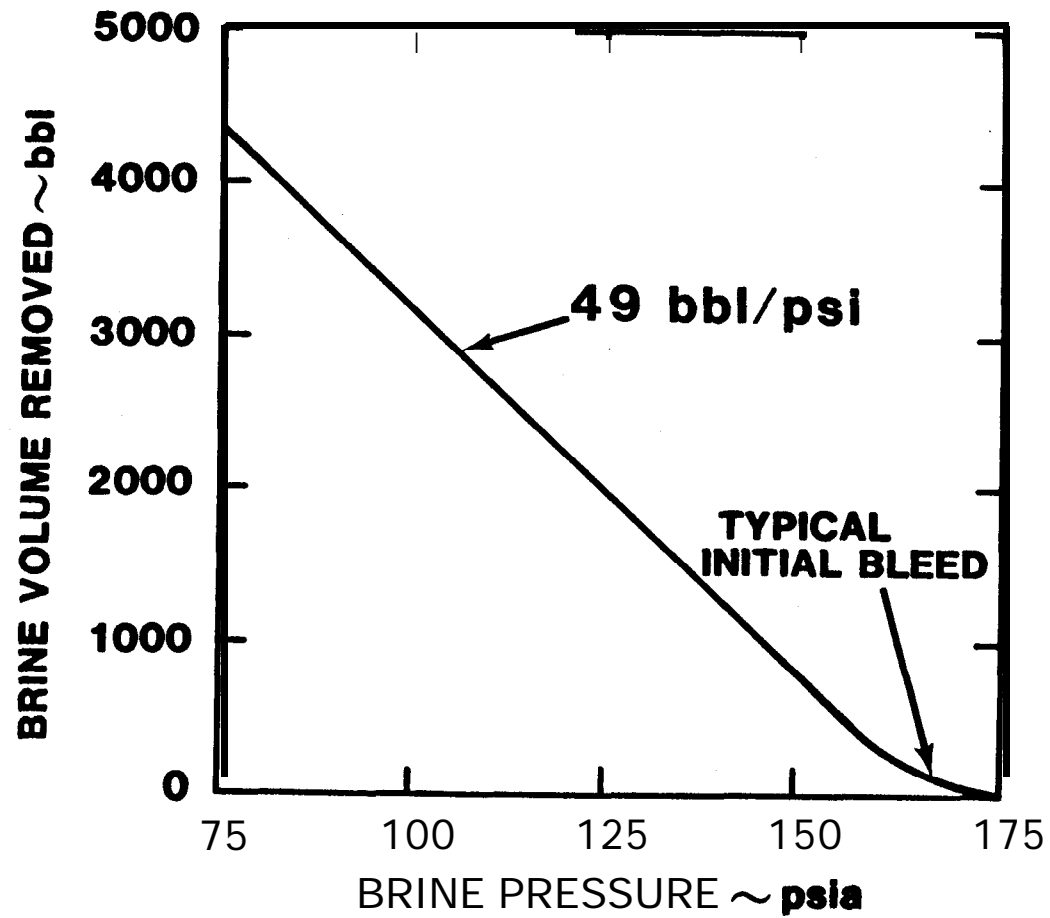
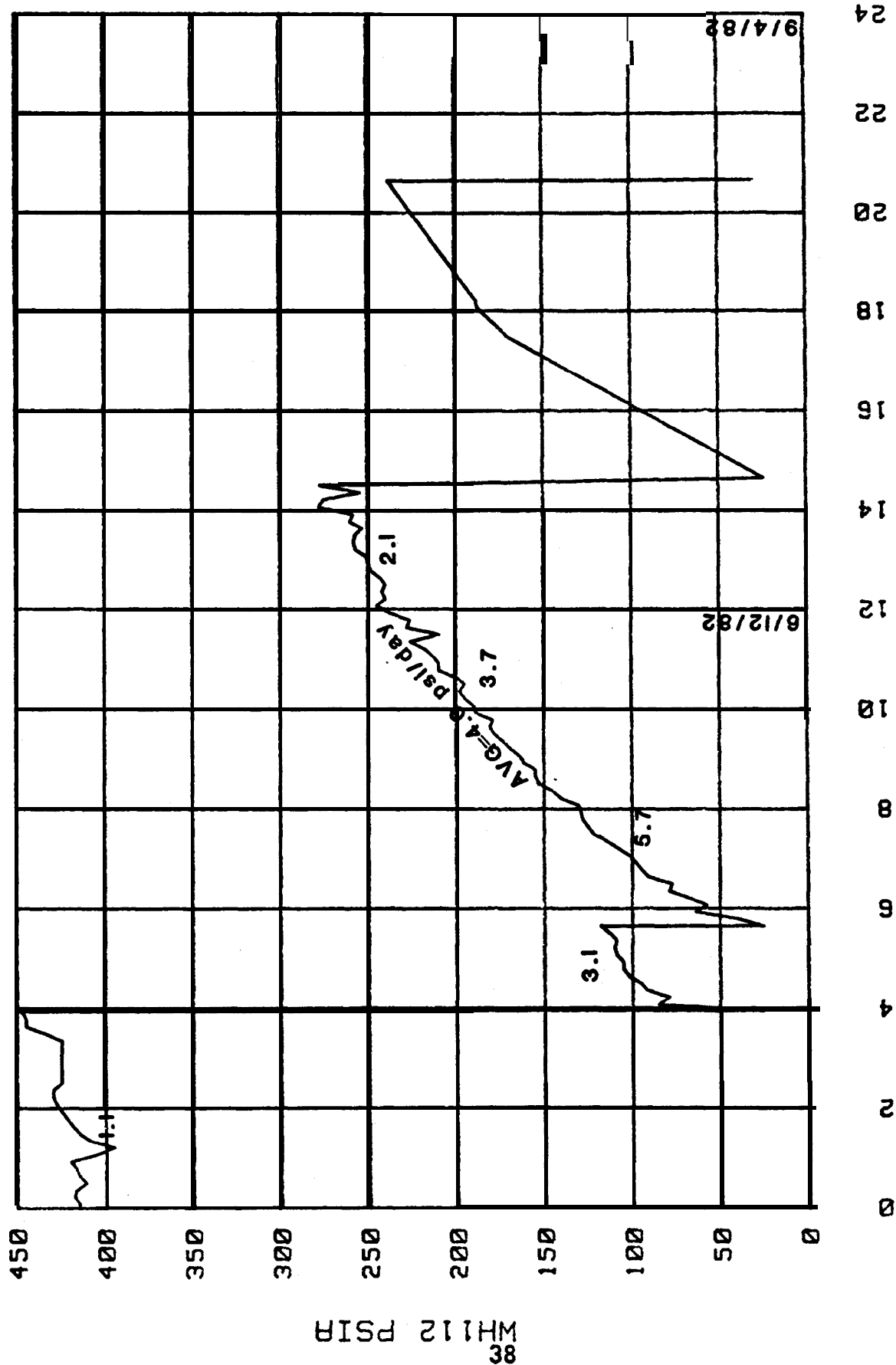
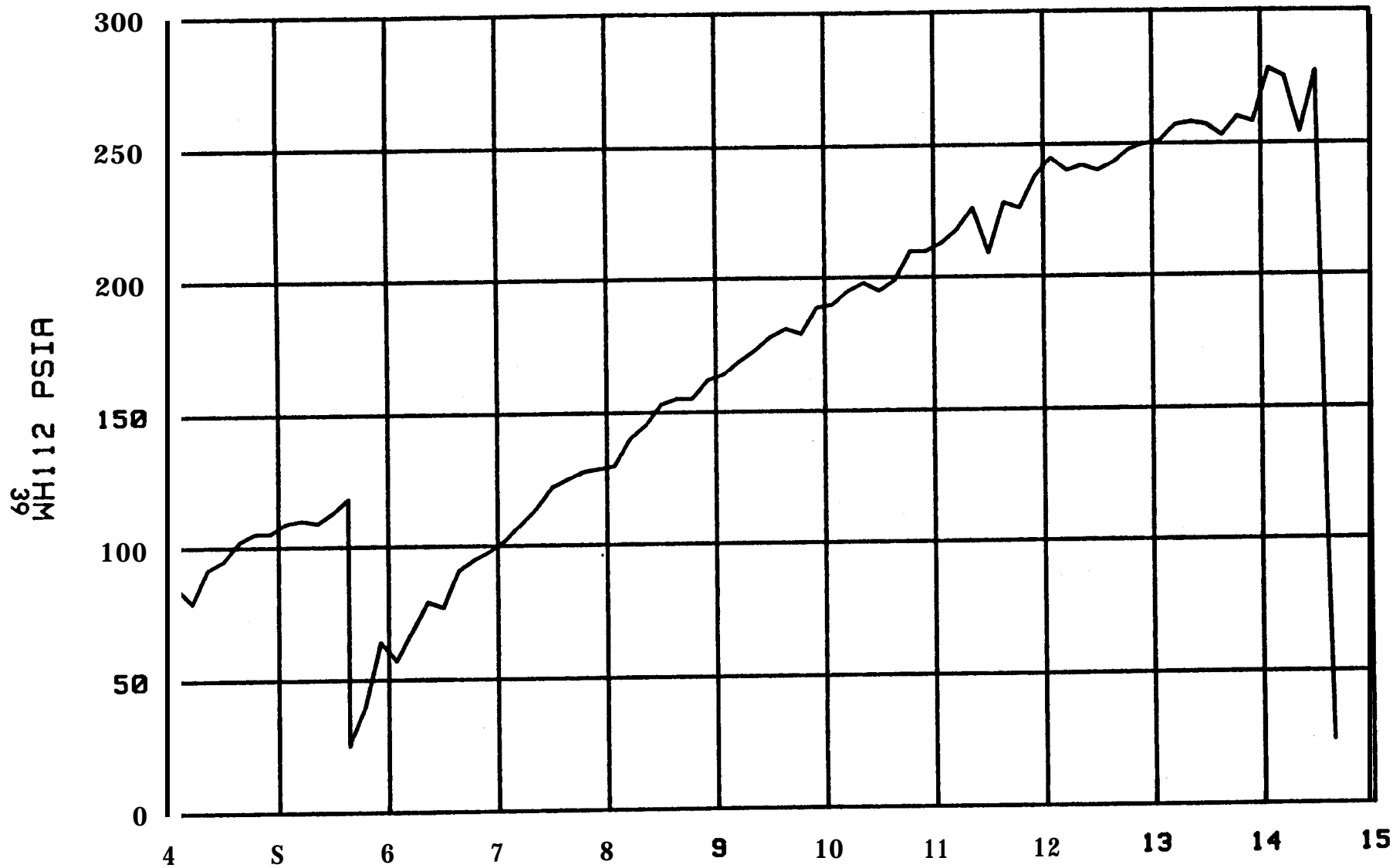


Figure 12.



TIME IN WEEKS 3/20/82 12:00 TO 8/11/82 15:00
FIG 13A WH112 PRESSURE VS TIME



WEEKS (0=3/20/82)
FIG 13B WH112 PRESSURE VS TIME

WH112 GALLON

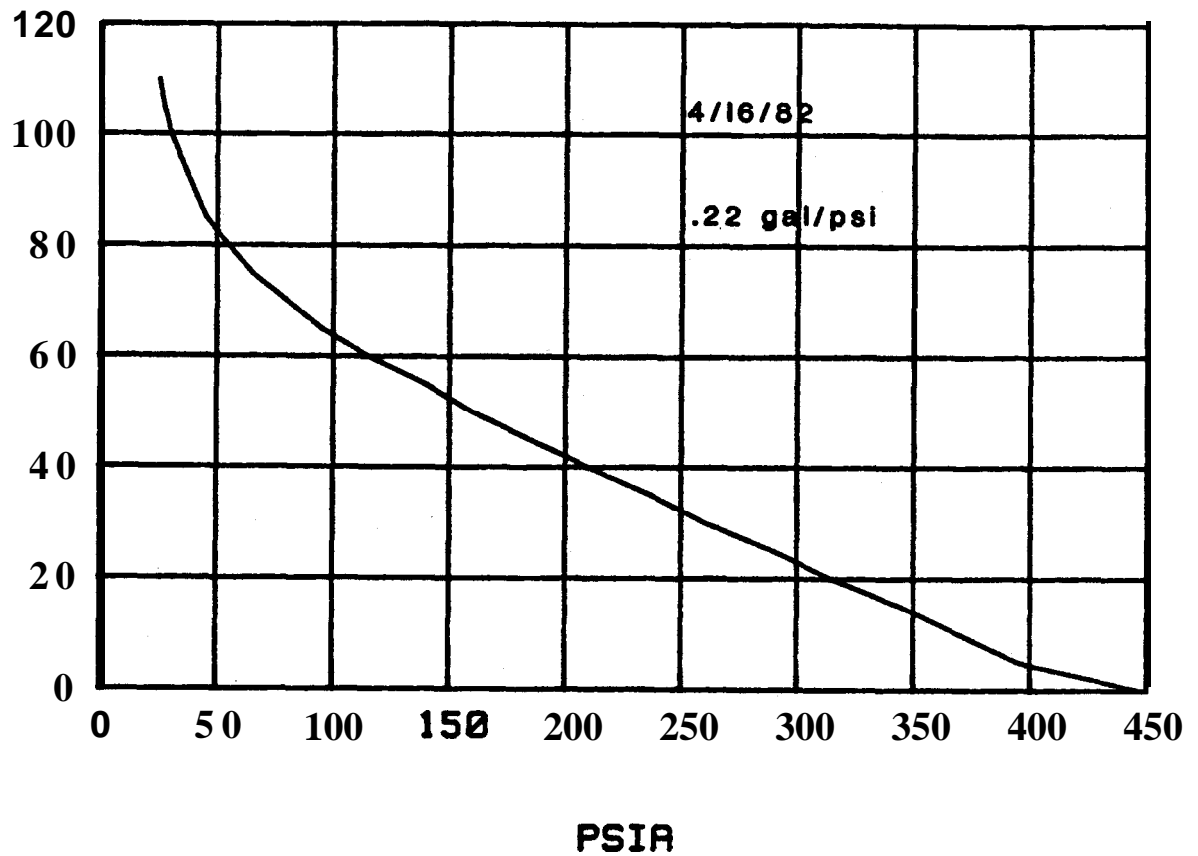


FIG 14A WH112 VOLUME REMOVED VS PRESSURE

WH112 GALLON

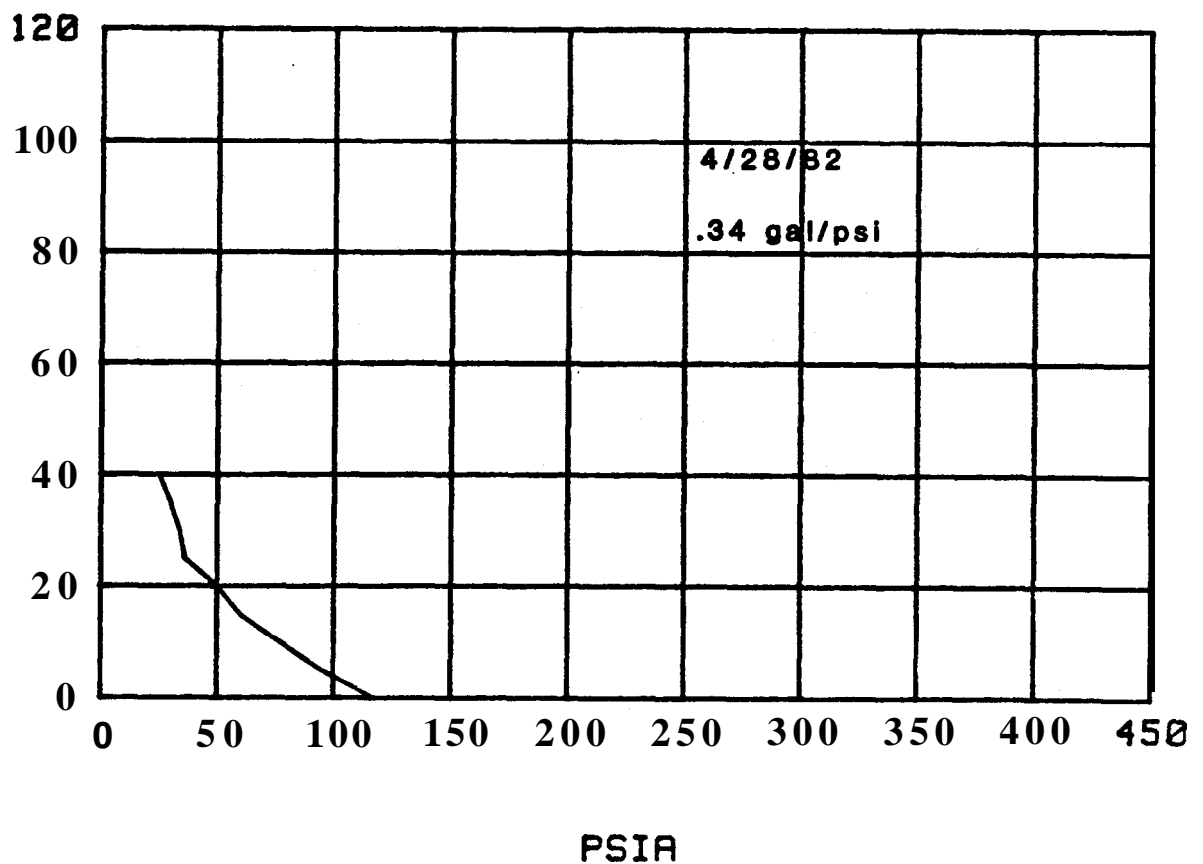


FIG 14B WH112 VOLUME REMOVED VS PRESSURE

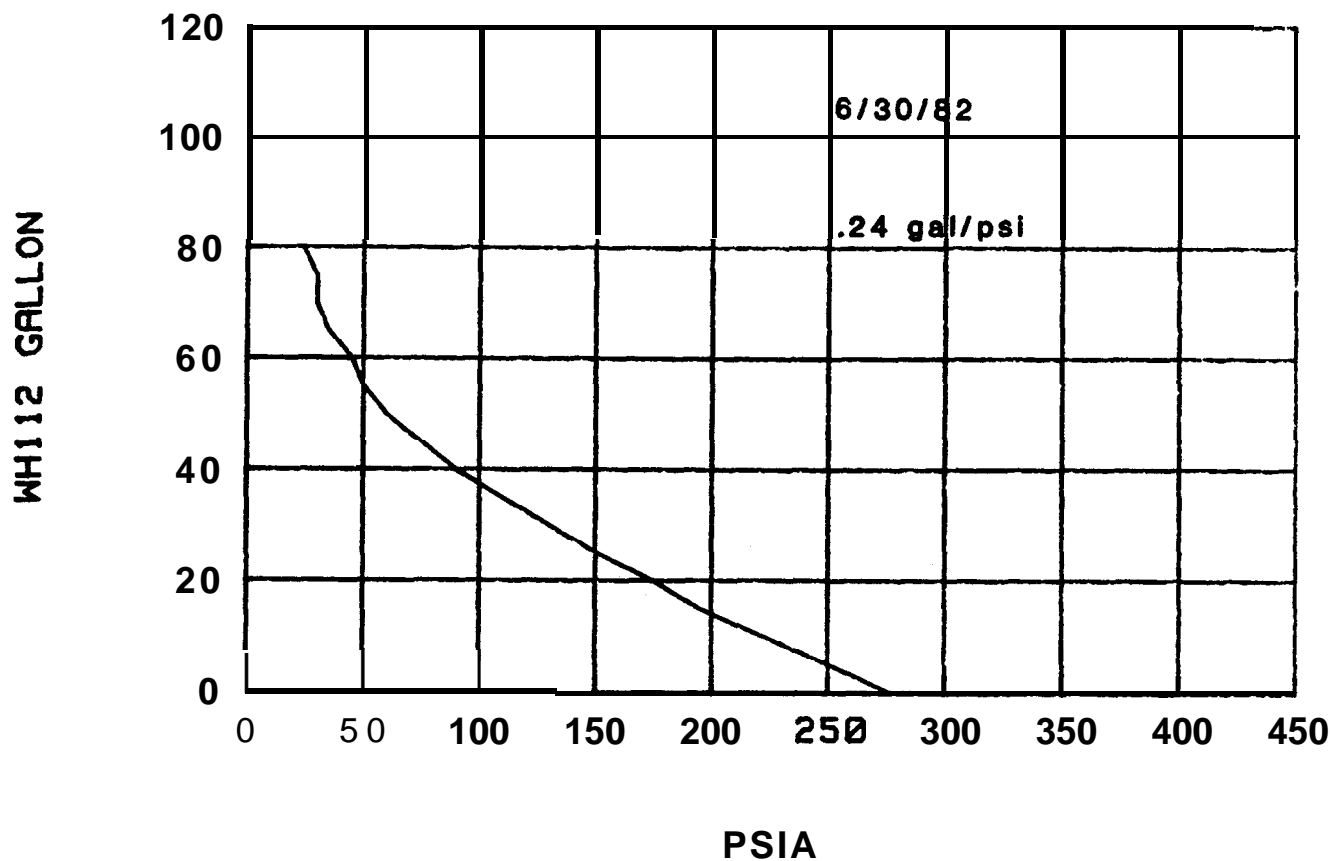


FIG 14C WH112 VOLUME REMOVED VS PRESSURE

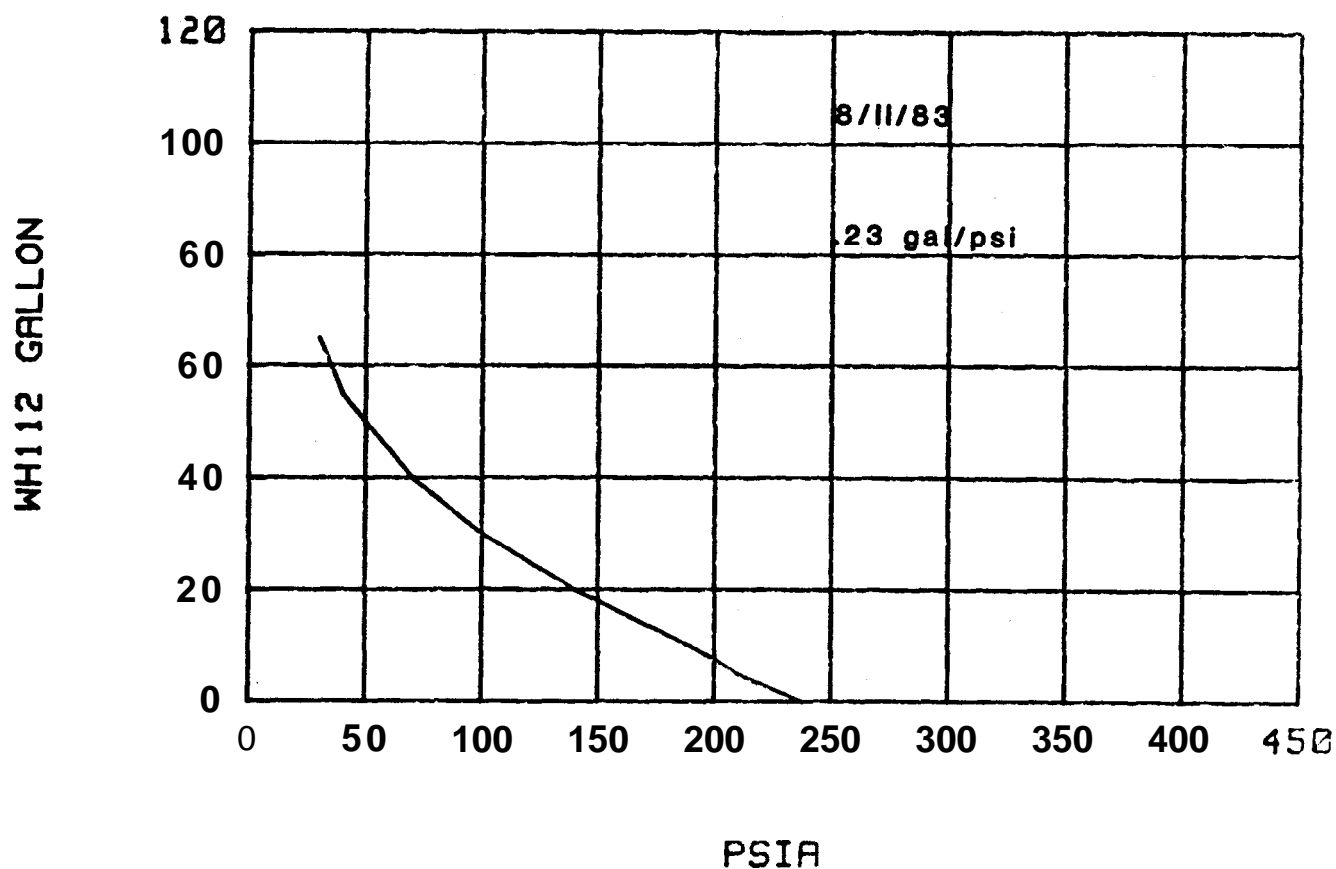


FIG 14D WH112 VOLUME REMOVED VS PRESSURE

Appendix I

Calculation of **Cavern Elasticity**

A. Assumptions

Oil Compressibility = $3.8 \times 10^{-6} \text{ V/V} \times \text{psi}$

Brine Compressibility = $2.15 \times 10^{-6} \text{ V/V} \times \text{psi}$

As shown in Figure A1

Elasticity is **made up of** liquid elasticity **and** salt elasticity.
Salt elasticity will be expressed in terms of volume change per total volume of the cavern per change in surface pressure:
[V/V]/psi.

The period of measurement of elasticity is short enough that changes in temperature and salinity and salt creep are negligible.

B. Procedure

Total measured volume/psi **minus** fluid compressibility times fluid **volume** all divided **by** total cavern volume.

C. Calculation of Salt Elasticity

SM 6 (Ref 8)

$$(9.7 \text{ bbl/psi})/5.63 \times 10^6 \text{ bbl} = 1.72 \times 10^{-6}$$

SM 7 (Ref 9)

$$(7.1 \text{ bbl/psi})/6.36 \times 10^6 \text{ bbl} = 1.16 \times 10^{-6}$$

SM 2-4-5 (Ref 10)

$$70 \text{ bbl/psi} - 2.15 \times 10^{-6} \times 13.57 \times 10^6 = 41$$

$$(41 \text{ bbl/psi})/13.57 \times 10^6 \text{ bbl} = 3.02 \times 10^{-6}$$

WH 6 (Ref 11)

$$(38.5 \text{ bbl/psi})/8.61 \times 10^6 \text{ bbl} = 4.47 \times 10^{-6}$$

BC 20 (Ref 12)

$$21.6 \text{ bbl/psi} - 2.15 \times 10^{-6} \times 5.2 \times 10^6 = 10.4$$

$$(10.4 \text{ bbl/psi})/5.2 \times 10^6 \text{ bbl} = 2.00 \times 10^{-6}$$

WH 1

$$49 \text{ bbl/psi} - 2.15 \times 10^{-6} \times .3 \times 10^6 - 3.8 \times 10^{-6} \times$$

$$8.2 \times 10^6 = 49 - 0.6 - 31.2 = 17.2$$

$$(17.2 \text{ bbl/psi})/8.5 \times 10^6 \text{ bbl} = 2.0 \times 10^{-6}$$

WH 112

Borehole volume

$$.3552 \text{ bbl/ft} \times 698 \text{ ft} + .3506 \times 599 + .3407 \times 1140 \text{ t}$$

$$.2975 \times 2597 = 1619 \text{ bbl}$$

$$.007 \text{ bbl/psi} - 2.15 \times 10^{-6} \times .001619 \times 10^6 = .004$$

$$(.004 \text{ bbl/psi})/1619 \text{ bbl} = 2.5 \times 10^{-6}$$

From :

Potter, Robert W., II and Brown, David L., "The Volumetric Properties of Aqueous Sodium Chloride Solutions From 0° to 500° at Pressure up to 2000 Bars Based on a Regression of Available Data in the Literature", Geological Survey Bulletin 1421-C, U. S. Government Printing Office, 1977.

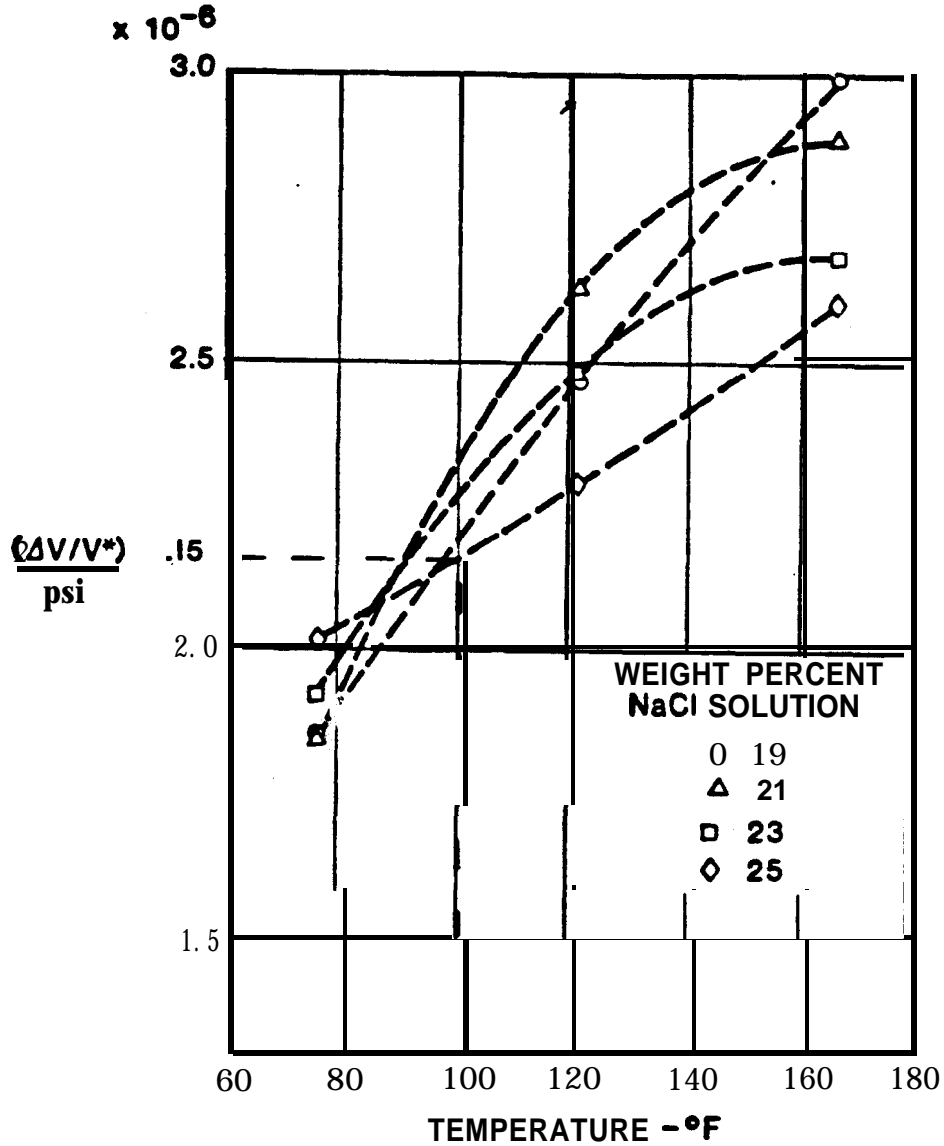


FIGURE A1. COMPRESSIBILITY OF BRINE
(V* IS VOLUME AT ATMOSPHERIC PRESSURE)

Appendix II.

Instrumentation Calibration

The pressure and flow instrumentation was calibrated before **the test began** and after **the test was completed**.

The 0 to 500 psia pressure transducer was calibrated as illustrated in Figure A-I. **The net change of** average transducer calibration error was from **-.06 psi** before **the test** to **t.23 psi** **after the test**. **This** small change in calibration error indicates **that these transducers** are acceptable for field tests and that no correction to the **test data** is required.

The flowmeter was calibrated as illustrated in Figure A-2. **There** appears to **be** a systematic error **between the Sandia** calibration and **the** Halliburton calibration **but** this error is small. **The** post test calibration **showed** less **than a 5% difference** in the test flowmeter relative to a **new** flowmeter. This small change in calibration error indicates that this flowmeter is **acceptable** for field **tests and that no** correction to **the test data** is required.

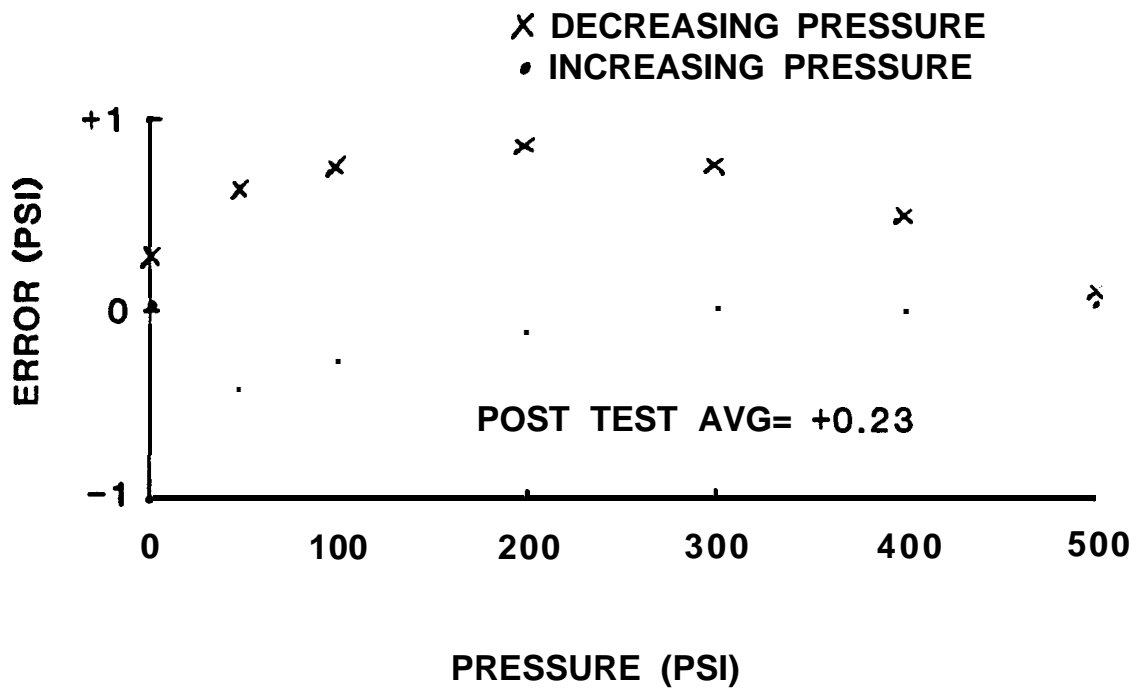
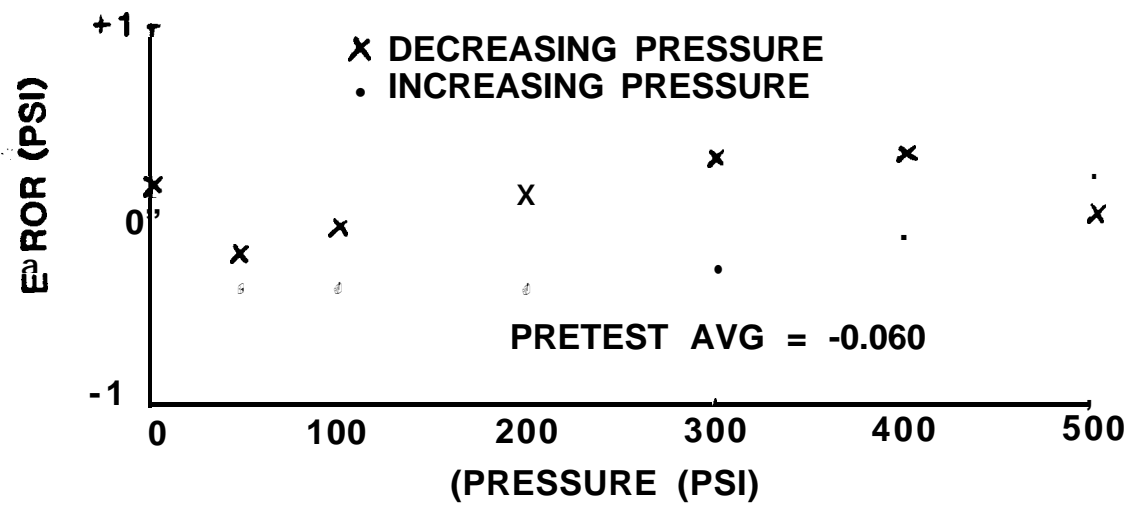


FIGURE A-2. PRESSURE TRANSDUCER CALIBRATION

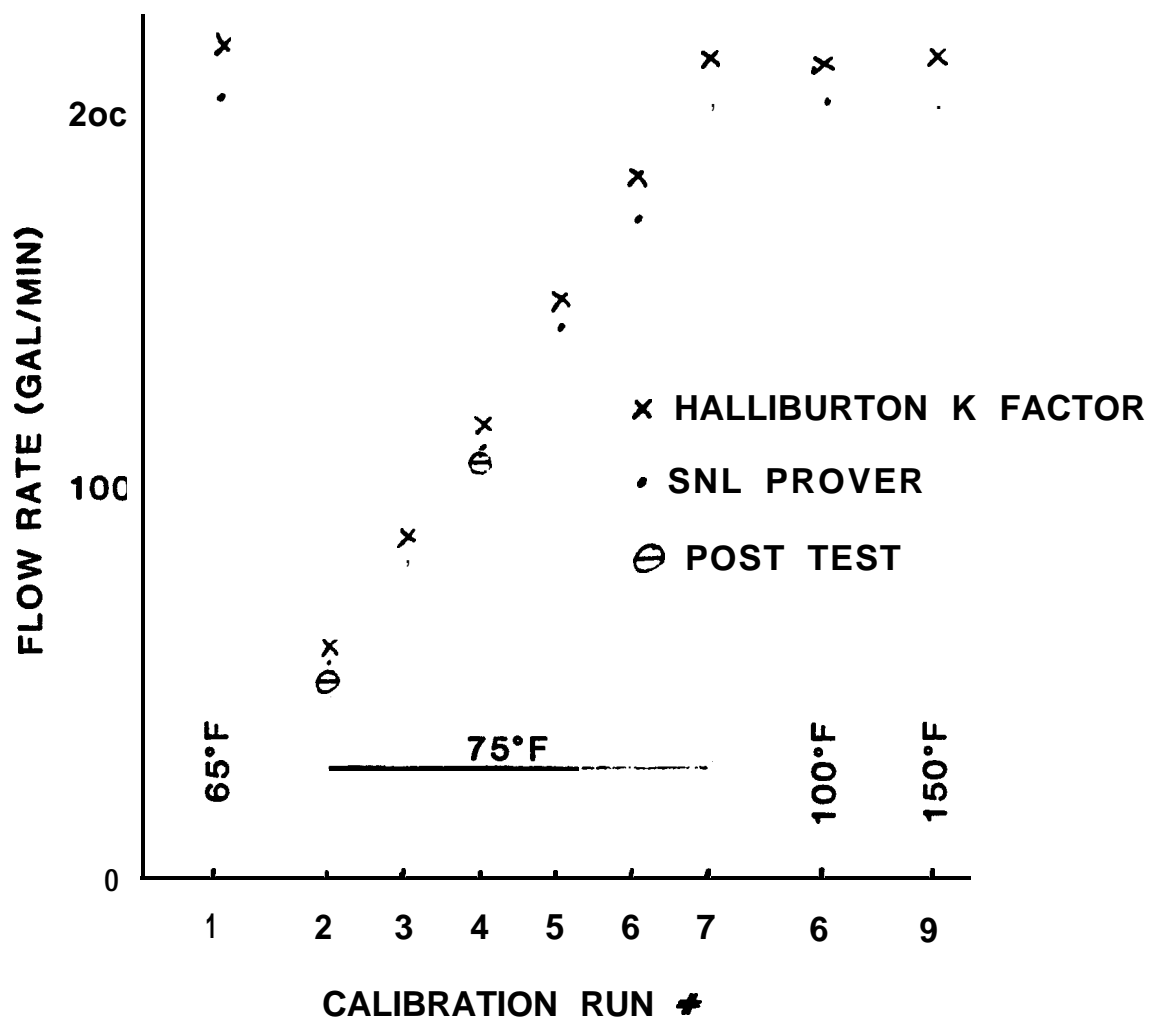


FIGURE A-3. HALLIBURTON FLOW METER CALIBRATION

Distribution:

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New Orleans, LA 70 123
Attn: E. E. Chapple, PMO-581 (6)
TDCS, L. Smith (2)

US Department of Energy (2)
Strategic Petroleum Reserve
1000 Independence Avenue SW
Washington, DC 20585
Attn: Dave Johnson
Dick Smith

US DOE (1)
Oak Ridge Operations Office
P.O. Box E
Oak Ridge, TN 37831
Attn: P. Brewington, Jr.

Aerospace Corporation (2)
800 Commerce Road East, Suite 300
New Orleans, LA 70123
Attn: K. Henrie
R. Merkle

Walk-Haydel 8 Associates
600 Carondelet
New Orleans, LA 70112
Attn: R. Haney

POSSI (2)
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6250	B. W. Marshall
6257	J. K. Linn (10)
6257	R. R. Beasley
6257	S. T. Wallace
6251	K. L. Coin
1512	J. C. Cummings
1521	R. D. Krieg
1542	B. M. Butcher
1821	N. E. Brown
8424	M. A. Pound
3141	C. Ostrander (5)
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3151	W. L. Garner (3)
3154-3	C. H. Dalin (25) DOE/TIC (Unlimited Release)